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Evaluation of Hydroacoustic Assessment Techniques for Chinook Salmon on the Kenai River using Split-beam Sonar

by

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Alaska Department of Fish and Game

Division of Sport Fish

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
ounce	oz
pound	lb
quart	qt
yard	yd
Spell out acre and ton.	

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
hour (spell out for 24-hour clock)	h
minute	min
second	s
Spell out year, month, and week.	

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
and	&
at	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
id est (that is)	i.e.,
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

alternate hypothesis	H_A
base of natural logarithm	e
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	F, t, χ^2, etc.
confidence interval	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
standard length	SL
total length	TL
variance	Var

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ABSTRACT

Dual-beam sonar has been used since June 1987 to estimate abundance of chinook salmon *Oncorhynchus tshawytscha* in the Kenai River. During 1994, a split-beam system was run concurrently with the dual-beam system to compare several performance attributes and to test assumptions and design parameters of the current dual-beam system. The split-beam system provided advantages in its ability to determine the direction of travel for each target and the spatial distribution of fish in the acoustic beam. The dual- and split-beam systems detected similar numbers of targets. Split-beam data confirmed earlier studies showing that fish were strongly oriented to the bottom of the acoustic beam during both runs, although vertical distribution did vary somewhat by direction of travel, tide stage, and season. Estimated proportions of downstream targets ranged from 9.5% to 15.7% for different data sets, substantially higher than the 3% to 5% estimated in previous studies. Contrary to previous studies, mean target strength appeared to provide little discriminatory power for separating Kenai River chinook from sockeye salmon due to high within- and between-fish variability.

Key words: Split-beam sonar, dual-beam sonar, chinook salmon, hydroacoustic, Kenai River, riverine sonar, standard target.

INTRODUCTION

Side-looking dual-beam sonar has been used to assess chinook salmon *Oncorhynchus tshawytscha* returns to the Kenai River since 1987. Chinook salmon support one of the largest and most intensively managed recreational fisheries in the state (Nelson 1994). Kenai River chinook salmon are among the largest in the world and have sustained in excess of 100,000 angler-days of fishing effort annually. Sonar estimates of inriver return provide the basis for estimating spawning escapement and implementing management plans that regulate harvest in competing sport and commercial fisheries for this stock. Implementation of these management plans has been a contentious issue for the state, one that commands much public attention. In recent years, some provisions of the management plan have been implemented which have resulted in significant fishery restrictions.

Hydroacoustic assessment of chinook salmon in the Kenai River is complicated by the presence of more abundant sockeye salmon *O. nerka* which migrate concurrently with chinook salmon. Dual-beam sonar was chosen for its ability to estimate target strength, which was to serve as the discriminatory variable to systematically identify and count only chinook salmon targets. To our knowledge, this was the first attempt to use this technology to discriminate between species in a riverine environment.

Distributions of hydroacoustic size (target strength) observed during developmental years of the project (1985-1986) had two distinct modes, which were assumed to originate from large chinook salmon versus sockeye/small chinook salmon (Paul Skvorc, Alaska Department of Fish and Game, Anchorage, personal communication). The trough between the two modes was chosen as a target strength threshold: only those fish with mean target strength above this value were counted as chinook salmon. During times of high sockeye abundance, a range threshold was also used; i.e., targets within a designated distance from the transducer were interpreted to be sockeye salmon and not counted. These two criteria have been the basis for discriminating between species and estimating the return of chinook salmon to the Kenai River.

Recent modeling exercises have called into question the feasibility of discriminating between chinook and sockeye salmon using target strength. Eggers (1994) performed stochastic computer simulations based upon Dahl and Mathisen's (1982) laboratory measurements of fish target strength which suggest that, theoretically, Kenai River chinook and sockeye salmon could not be differentiated using mean target strength due to high within-fish variability. Eggers et al. (1995) noted that, based on generally accepted models of fish target strength versus size, the lower modes of the 1985-1986 target strength distributions were probably too low to be sockeye salmon. However Eggers et al. (1995) concluded that the dual-beam sonar estimates of chinook salmon passage into the Kenai River were still credible. They based their conclusions on the similarity in target strength distributions between times when sockeye abundance in the river was grossly different, and consistencies between sonar estimates of passage with those from mark-recapture experiments and with gillnet CPUE data. They hypothesized that discrimination between species was achieved primarily because of spatial segregation, sockeye salmon near shore and chinook salmon mid-river, and that the range thresholds in place had effectively prevented substantial numbers of sockeye from being counted.

In 1994, we conducted more rigorous experiments to test important assumptions and design parameters of the current dual-beam sonar configuration. Key to our ability to design more definitive experiments in this observational study was the recent availability of split-beam sonar. Split-beam sonar provides several important advancements over dual-beam technology for riverine applications, most notably the ability to estimate the three-dimensional position of a target in space. This capability allows the direction of travel of each target to be determined as well as the trajectory of the target as it moves through the acoustic beam. The data-processing capabilities of split-beam systems have only recently been developed to the point where they are comparable to those available for dual-beam sonar.

We deployed such a split-beam system side-by-side with the dual-beam system for much of the 1994 season. In this report our objectives are to:

1. compare several performance attributes of the split- and dual-beam systems,
2. describe the spatial distribution of targets passing through the acoustic beam using split-beam sonar and compare these results with previous studies that used downward looking sonar,
3. estimate the proportion of targets traveling downstream using split-beam sonar and compare these estimates with previous studies using alternate techniques,
4. reassess the feasibility of using target strength measurements to discriminate chinook salmon from sockeye salmon, and
5. assess the credibility of dual-beam sonar estimates of chinook salmon passage.

We also provide recommendations for future program direction. Estimates of 1994 chinook salmon passage, generated from the dual-beam sonar system, are presented in a separate report (Burwen and Bosch *In press*).

METHODS

BIOLOGICAL AND PHYSICAL SETTING

The Kenai River has two stocks of chinook salmon: an early run which enters the river from mid-May through June, and a late run which enters the river from late June through early August (Burger et al. 1985). Each run is managed independently and statistics are compiled by run.

The Kenai River also supports early and late runs of sockeye salmon. Sockeye returns mirror the timing of the early and late-run chinook. Most of the early-run sockeye migrate to the Russian River, and have numbered from 5,460 to 215,710 since 1963 (Nelson 1994). Late-run sockeye are destined for spawning locations throughout the Kenai River drainage and are far more numerous. Total abundance of late-run sockeye, estimated with sonar at river mile 19, has ranged from 285,000 to 1,598,000 since 1977 (Nelson 1994).

Both the split-beam and the dual-beam systems were deployed at the river mile 8 sonar site, which has been used since the mid 1980s (Figure 1). This site was originally selected for its acoustically favorable characteristics, its location relative to the riverine sport fishery, and its location relative to known chinook spawning sites. At this site the river has a single channel with a uniformly-sloping, absorptive bottom from each bank to the center of the channel. The amount of boat traffic and associated boat wake, which interferes with sonar, is somewhat reduced because the site is downstream from the highest concentration of sport fishing effort. The site is also below the lowest suspected mainstem spawning sites for chinook salmon (Alexandersdottir and Marsh 1990) which reduces the incidence of chinook salmon loitering in the sonar beam or returning downstream. One disadvantage of the site is that it is located within tidal influence, with the current reversing during some high tides. Although previous studies have shown only small proportions (< 5%) of downstream migrants (Eggers et al. 1995), the effect of tidal cycles on fish distribution and direction of travel has remained a concern.

Sample Design

Experimental split-beam data were collected jointly with the standard dual-beam data used to provide estimates of chinook salmon abundance for fishery management purposes. The dual-beam sonar system was deployed and operated from 15 May to 7 August in the same manner as in previous years (Burwen and Bosch *In press*). The right and left bank were each sampled for 20 minutes per hour, the right bank from the top of each hour until 20 minutes after, the left bank from 25 minutes until 45 minutes after the hour. The system was idle the remaining 20 minutes per hour. This routine was followed 24 hours per day, 7 days per week.

The split-beam system was operated essentially continuously on the right bank only, 24 hours per day, from 12 June until 4 August. Split-beam data collection was first directed toward meeting objective (1), specifically to determine whether the dual- and split-beam systems produced comparable counts of fish and comparable measurements of individual fish. To do so, the split-beam system was deployed immediately adjacent to the dual-beam system so that individual fish could be ensonified by both systems. A relatively high voltage threshold, which could be maintained throughout all tide stages, was used. Such data collection continued until early July.

For the remainder of the season we attempted to collect data at lower voltage thresholds, which was desirable in order to address objective (4). Although the system was collecting data continuously, high quality low-threshold data could only be obtained during the rising tide when background interference from bottom and surface noise was low, and on Mondays when boat traffic was prohibited.

Dual-Beam Sonar Operation

The main components of the dual-beam sonar system are listed in Table 1. See Burwen and Bosch (*In press*) for a description of auxiliary equipment.

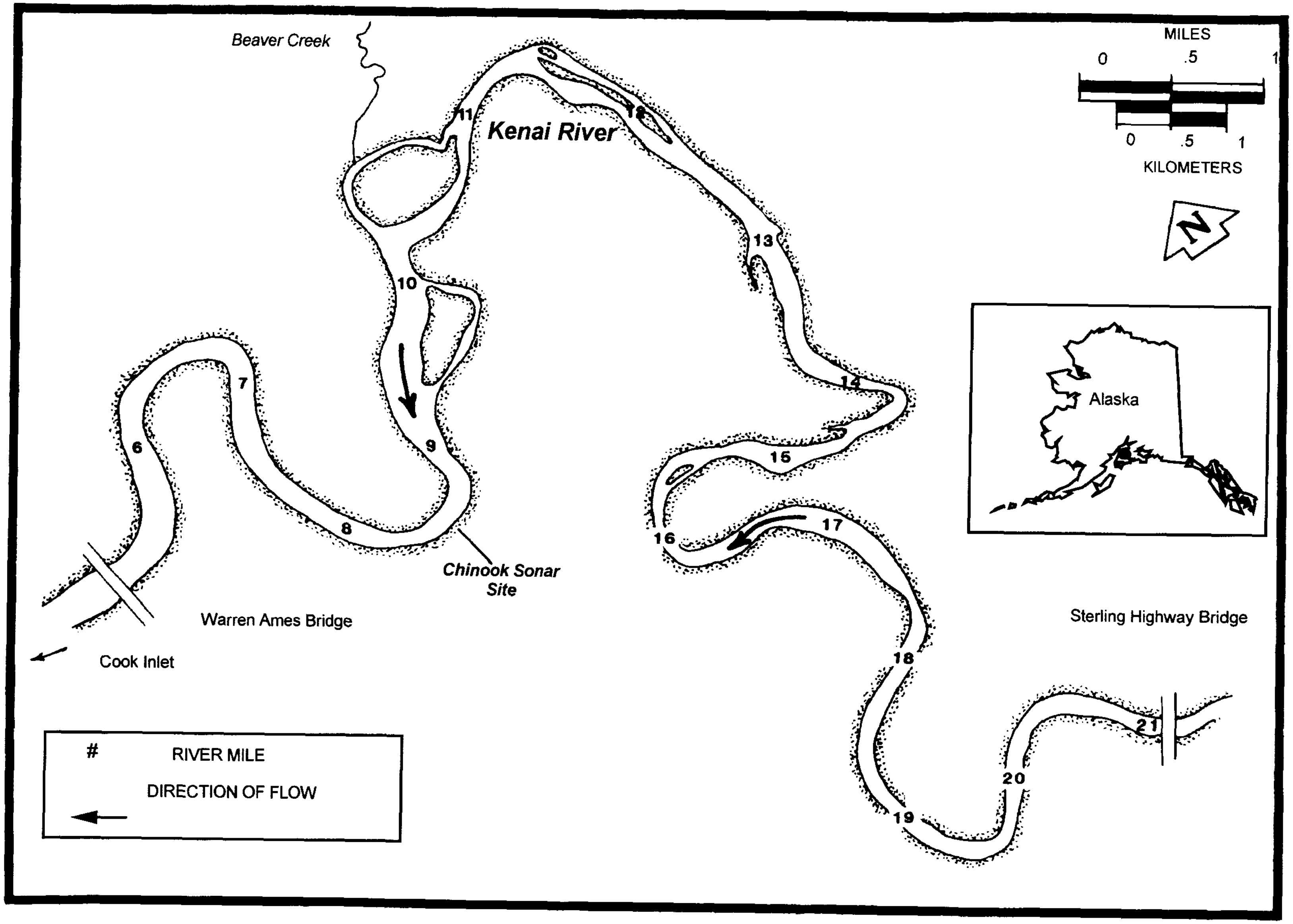

Figure 1.- Location of Kenai River chinook salmon sonar site.

Table 1.-Principal components of the dual- and split- beam systems used in the 1994 comparative study.

System Component	Dual-Beam	Split-beam
Frequency	420 kHz	200 kHz
Sounder	Biosonics Model 102 Dual-beam Echosounder	Hydroacoustics Technology Inc. (HTI) Model 240 Split-Beam Echosounder
Signal Processor	Model 281 Echo Signal Processor based in a Compaq 386 20e personal computer	Model 340 Digital Echo Processor based in a Leading Edge 486 personal computer
Transducers	(1)Biosonics Dual-Beam nominal beam widths: narrow beam : 3^{o}x8.2^{o} wide beam: 6^{o}x17.4^{o}	(2) HTI Split-Beam nominal beam widths: 2.9^{o}x10.2^{o} nominal beam widths: 4.4^{o}x8.9^{o} (not used)
Multiplexer	Biosonics Model 151	Same (shared)
Chart Recorder	HTI model 403 digital dual-channel chart recorder	Same (shared)
Video Display	Simrad Model CF-100 color video monitor	Same (shared)
Remote Pan and Tilt Aiming Controller	Biosonics Model SP500 Rotator Control Box	Remote Ocean Systems Model PTC-1 Pan and Tilt Controller
Remote Pan and Tilt Aiming Unit	Biosonics Model SP500 Rotator Axes	Remote Ocean Systems Model P-25 Remote Pan and Tilt Unit

One elliptical, dual-beam transducer was mounted on each of two steel tripods. At the start of the season the transducer tripods were placed on each bank in a position close to shore but still submerged at low tide (Figure 2). As the water level rose throughout the season, the tripods were periodically moved closer to shore so that the total range ensonified by the sonar beams increased from approximately 75 m early in the season to approximately 100 m later.

The vertical and horizontal aiming angles of each transducer were remotely controlled by the dual-axis electronic pan and tilt system. In the vertical plane, the transducer was aimed so that the sonar beam lightly grazed the bottom of the river. In the horizontal plane, the transducer was aimed perpendicular to the flow of the river current in order to maximize the probability of ensonifying fish from a lateral aspect.

Digitized electronic dual-beam data were filtered by the Echo Signal Processor (ESP) to eliminate echoes with narrow-beam voltage less than a threshold of 900 millivolts (mV), equivalent to a -35.0 decibel (dB) target on the maximum response axis. Data were written to computer disk following Burwen and Bosch (*In press*). Paper chart recordings were printed for each 20-minute sample. The chart recorder was set to display all echoes greater than 636 mV, 3 dB less than the ESP threshold.

The number of fish per sample was determined by using both the electronic, partially filtered data output by the ESP and the paper chart recordings. Specially developed software (Burwen and Bosch *In press*) was used to perform additional filtering of individual echoes and to perform initial tracking (grouping of echoes into targets, Appendix A1). Results were compared with paper chart recordings to ensure tracking accuracy and to eliminate obvious debris. Debris typically left long straight traces on the chart recordings, and had echoes with extreme pulse widths.

Dual-beam techniques were used to estimate the target strength of individual echoes (Appendix B1). Echo target strength values (in dB) were averaged to obtain mean target strength for each fish.

Split-Beam Sonar Operation

Principal components and features of the split-beam sonar system are listed in Table 1, where they can be compared with equivalent dual-beam components.

The 4.4^0 x 8.9^0 transducer was used only briefly, at the beginning of the season. It proved to be too wide in its vertical dimension during low tide stages, so the 2.9^0 x 10.2^0 transducer was used thereafter.

From 12 June until 13 July, the split-beam transducer was deployed immediately downstream (tripod legs overlapping, less than 2 feet separation) of the right-bank dual-beam transducer, in order to collect paired dual- and split-beam data on the same fish targets. The split-beam and the dual-beam systems were triggered simultaneously by the multiplexer. Cross-talk (unwanted signals from the opposite sonar system) between the two systems sometimes required that the split-beam aim be slightly offset (less than 3 degrees) to avoid creating duplicate targets on the dual-beam system.

On 13 July, the split-beam tripod was moved 3-5 m downstream from the dual-beam transducer, and it remained in this configuration until the end of split-beam data collection on 4 August.

The digital echo sounder (DES) sent the data from each returned echo to the digital echo processor (DEP). The DEP performed the initial filtering of returned echoes based on user-selected criteria (Appendix C1), and recorded the start time, date and number of pings processed

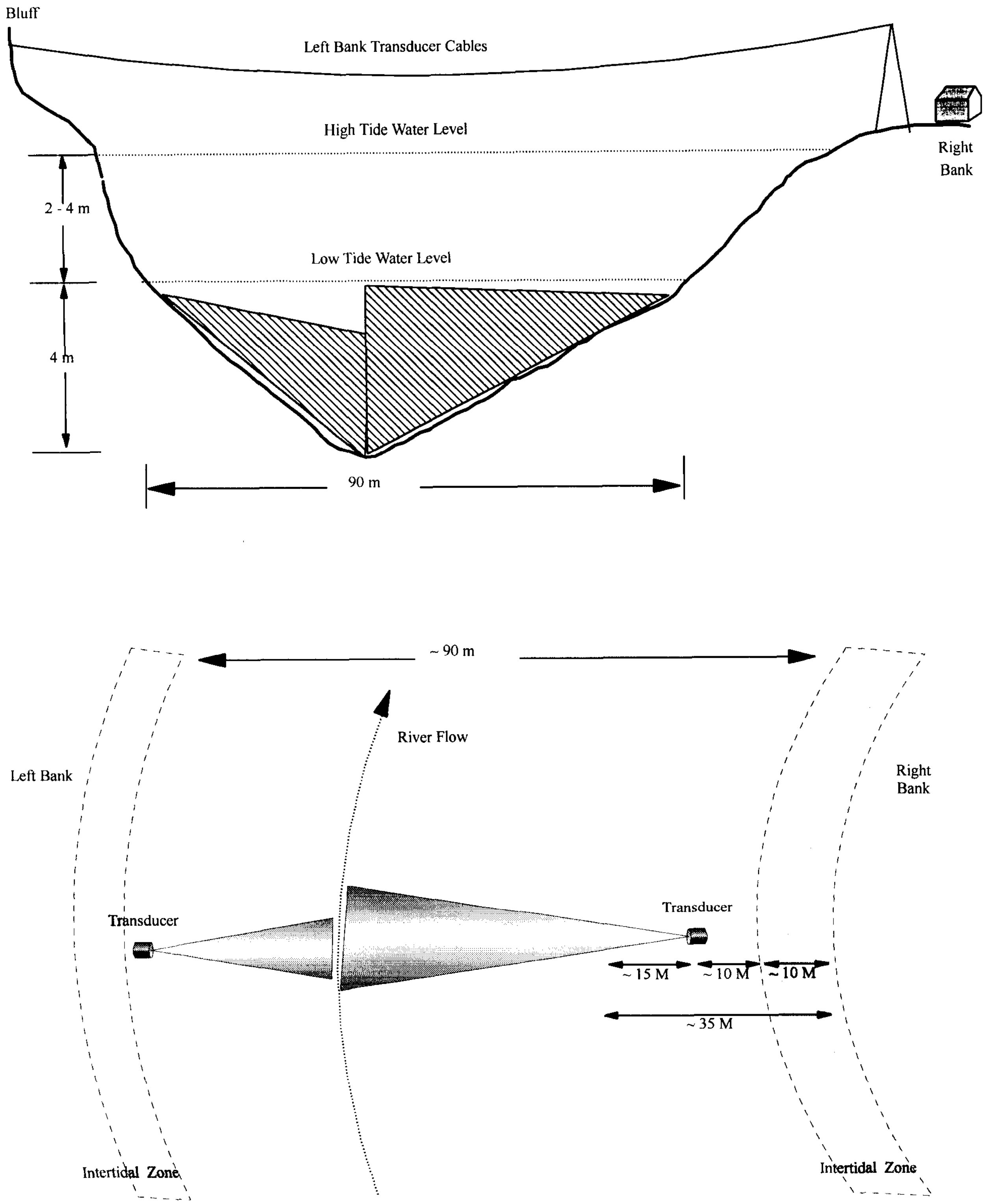

Figure 2.-Cross-sectional (top) and overhead (bottom) view of Kenai River chinook salmon sonar site showing ensonified portion of the river.

for each sample. As with the dual-beam system, a voltage threshold (see below) was used to filter data at this level. Minimum vertical and horizontal off-axis values of 1.8° and 6.0° were used to prevent consideration of unreliable data from transducer side lobes. For each echo passing initial filtering criteria, information was written to computer disk. The sum channel split-beam data from the Model 240 DES was also printed out on a dot matrix printer using a Model 403 Digital Chart Recorder. The chart recorder voltage threshold was set equal to the DEP threshold.

The DEP used software, with user-selected parameters, to perform additional filtering of echoes and to group filtered echoes into targets. Echoes belonging to each tracked target were written to computer disk as a file with extension .ECH, and summary information for each target was written to a file with extension .FSH (Appendix D1). Results were compared with paper chart recordings to ensure tracking accuracy and to eliminate debris.

Split-beam techniques were used to estimate target strength of individual echoes (Appendix B1). Echo target strength values (in dB) were averaged to obtain mean target strength for each fish.

Calibration

Both systems were professionally calibrated by Alliant Tech Systems[1] in Seattle. Target strength measurements were also obtained from a 38.1 mm tungsten carbide sphere (Foote and MacClennan 1984) at the calibration facility. At the sonar site, we measured the same standard sphere *in situ* by suspending it from monofilament line in the acoustic beam. For each system, we performed such *in situ* calibration verifications twice more during the season to measure any drift in performance. For each calibration verification, we recorded the maximum background noise level and voltage threshold in addition to the data collected automatically by each system.

Voltage Threshold Settings

Voltage thresholds for data acquisition must be set high enough to exclude background noise from sources such as boat wake, the river bottom, and the water's surface. Collection of data from unwanted noise causes data management problems and also makes it difficult to distinguish echoes originating from valid fish targets. The amount of background noise is determined largely by the dimensions of the sonar beam in relation to the depth of the river. Since the water level at the sonar site is strongly influenced by tidal stage (vertical fluctuations of more than 4 m), the amount of background noise fluctuates periodically, with lowest noise levels during high tide and the highest levels during low tide. Voltage thresholds could be lowered substantially as the water level rose. This enabled the detection of more echoes from valid targets. However, there are disadvantages to using a constantly changing threshold; for instance, target strength measurements made at two different thresholds are not comparable due to the effects of threshold-induced bias (MacClennan and Simmonds 1992). So for most data collection (all dual-beam data, split-beam data before 4 July) the threshold was set just high enough to exclude background noise at the lowest tide, when noise was at a maximum. This threshold (-35 dB dual-beam, -33.8 dB split-beam) could therefore be used at all tide stages. Beginning on 4 July, the split-beam system threshold was lowered during higher tide stages so as to collect data at the lowest thresholds possible.

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[1] Mention of a company's name does not constitute endorsement.

DATA SETS

Dual-beam data were checked for tracking accuracy in the course of generating daily passage estimates inseason. With the split-beam data, however, the time-consuming process of tracking and hand-checking for accuracy had to be done postseason. Therefore, although the split-beam system was operated continuously 24 hours a day from 12 June until 4 August, only a portion of the data could be processed for analysis in the time available. Boat traffic and tidal fluctuations also limited the amount of low-threshold data which could be collected. Three data sets were analyzed for this report. Because these data were sampled from only portions of the season, inferences drawn from them are limited in scope to the time frame during which they were collected.

Split-Beam versus Dual-Beam Comparison Data

Data from 4 days (1-3 July, 5 July; Table 2) were compared with chart recordings to pair each target tracked by split-beam sonar with its counterpart tracked by dual-beam sonar. Data collection voltage thresholds were -35 dB for the dual-beam system and -32 dB for the split-beam system. The split-beam threshold was set 3 dB higher than the dual-beam threshold because the split-beam sonar measured a standard sphere approximately 3 dB larger than did the dual-beam system, and we wished to equalize the effect of threshold-induced bias between systems.

A total of 175 targets were tracked by both systems. An additional 47 targets were tracked by one system only, and/or were recovered when chart recordings were consulted. Target strength measurements were readily available only for the 175 targets tracked by both systems. Of these targets, we eliminated 30 which differed in range by more than 2 meters in order to reduce the probability that two different targets were paired. We used the remaining 145 targets to compare target strength measurements between systems.

Split-Beam High and Low Threshold Data

We processed 11 days of split-beam data collected in June and July at a relatively high voltage threshold (-33.8 dB) similar to the standard threshold used with the dual-beam system (Table 3).

Additional split beam data were collected at lower thresholds (-40.8 to -38.9 dB) on 4 July and 18 July (Table 4). In general, this threshold could only be maintained during certain tide stages on Mondays, when there was no boat traffic. The 2 days of low-threshold data contrast greatly in the

Table 2.-Dates and sample times of data used for dual- and split-beam sonar comparison.

Date	Sample Times	Targets
7/1	0000, 0100, 0200, 0300, 0500, 1100, 1200, 1300, 2000, 2200	68
7/2	0100, 0200, 0300, 0400, 0500, 1200, 1300, 1400, 2200, 2300	46
7/3	0100, 1300, 1400, 1500, 1700	50
7/5	0300, 1500	11

Table 3.-Split-beam data collected at a high voltage threshold, equivalent to a -33.8 dB target on-axis.

Date	Targets	Tide Stages Sampled
Early Run		
6/13	160	rising, falling, low
6/20	165	rising, falling, low
6/27	262	rising, falling, low
6/29	404	rising, falling, low
Total	991	
Late Run		
7/1	60	rising, falling
7/2	49	rising, falling
7/3	80	rising, falling
7/4	427	rising, falling, low
7/5	11	rising
7/11	127	rising, falling, low
7/18	656	rising, falling, low
	1,410	

number of sockeye salmon present. On 4 July there were few sockeye salmon in the river, while on 18 July the sockeye passage rate was high (see mile-19 sockeye sonar counter passage estimates, Table 5).

ANALYTICAL METHODS

Analytical methods are described along with the results and discussion specific to each individual objective, each of which is addressed in turn below.

Table 4.-Split-beam data collected at lower voltage thresholds.

Date	Targets	Threshold	Tide Stages Sampled	Relative Sockeye Abundance
7/4	469	-38.9 dB	rising, falling, low	low
7/18	624	-38.9 to -40.8 dB	rising, a few on the falling	high

Table 5.-Daily estimates of sockeye salmon passing the rm 19 sockeye sonar site in the Kenai River, 1994.

Date	Number of Sockeye	Date	Number of Sockeye
02-Jul	399	29-Jul	7,860
03-Jul	301	30-Jul	9,935
04-Jul	534	31-Jul	19,493
05-Jul	1,091	01-Aug	55,382
06-Jul	859	02-Aug	95,473
07-Jul	4,022	03-Aug	53,274
08-Jul	3,522	04-Aug	23,549
09-Jul	2,495	05-Aug	16,884
10-Jul	2,403	06-Aug	14,713
11-Jul	3,003	07-Aug	12,394
12-Jul	2,200	08-Aug	7,796
13-Jul	1,858	09-Aug	9,241
14-Jul	2,145	10-Aug	13,434
15-Jul	7,204	11-Aug	20,892
16-Jul	30,546	12-Aug	22,260
17-Jul	10,369	13-Aug	21,054
18-Jul	49,484	14-Aug	22,078
19-Jul	41,634	15-Aug	17,841
20-Jul	26,201	16-Aug	21,482
21-Jul	42,744	17-Aug	18,149
22-Jul	37,055	18-Aug	11,871
23-Jul	29,363	19-Aug	16,437
24-Jul	45,222	20-Aug	21,492
25-Jul	55,772	21-Aug	13,544
26-Jul	20,567	22-Aug	8,094
27-Jul	8,027	23-Aug	6,578
28-Jul	4,761	24-Aug	8,465

From: Reusch and Fox 1995

RESULTS AND DISCUSSION

The primary motive for considering the change from dual-beam to split-beam sonar was to derive the benefits of determining the 3-dimensional location and direction of travel of each individually-tracked target. Knowing the location of targets as they transit the beam facilitates *in situ* calibration verification, allows estimation of target spatial distribution, and provides additional information that may be used in trouble-shooting and verifying proper operation of the equipment. Direction-of-travel information should improve the accuracy of chinook salmon passage estimates by accounting for the positive bias due to a previously unknown downstream component. Although we make other comparisons of the two sonar systems used in this study, these comparisons are made only to identify large disparities in target detection or target strength measurement that would affect the continuity of historical data. They are not a rigorous comparison between dual- and split-beam technologies, especially since the two systems used in this study differed in operating frequency. Dual-beam and split-beam techniques are described in greater detail by Ehrenberg (1983). Analytical and theoretical comparisons of dual- and split-beam techniques can be found in Traynor and Ehrenberg (1990), and Ehrenberg (1979, 1983).

OBJECTIVE 1: SYSTEM PERFORMANCE

In theory, split-beam sonar offers several potential improvements over dual-beam sonar for riverine applications. In addition to identifying the 3-dimensional location and direction of travel for each target, theoretical (Ehrenberg 1983) and analytical (Traynor and Ehrenberg 1990) studies have concluded that split-beam sonar performs better than dual-beam sonar in the presence of noise. The split-beam system leased in 1994 also operated at a lower frequency (200 kHz) than the existing dual-beam system (420 kHz), and should therefore exhibit reduced sonar signal attenuation at long ranges (MacLennan and Simmonds 1992). In order to assess the suitability of 200 kHz split-beam sonar as a replacement for the existing 420 kHz dual-beam sonar, we needed to determine the extent to which the potential advantages applied to our application. In addition, we needed to compare the fish counts and measurements obtained from both systems in order to preserve the continuity of the historical database as much as possible.

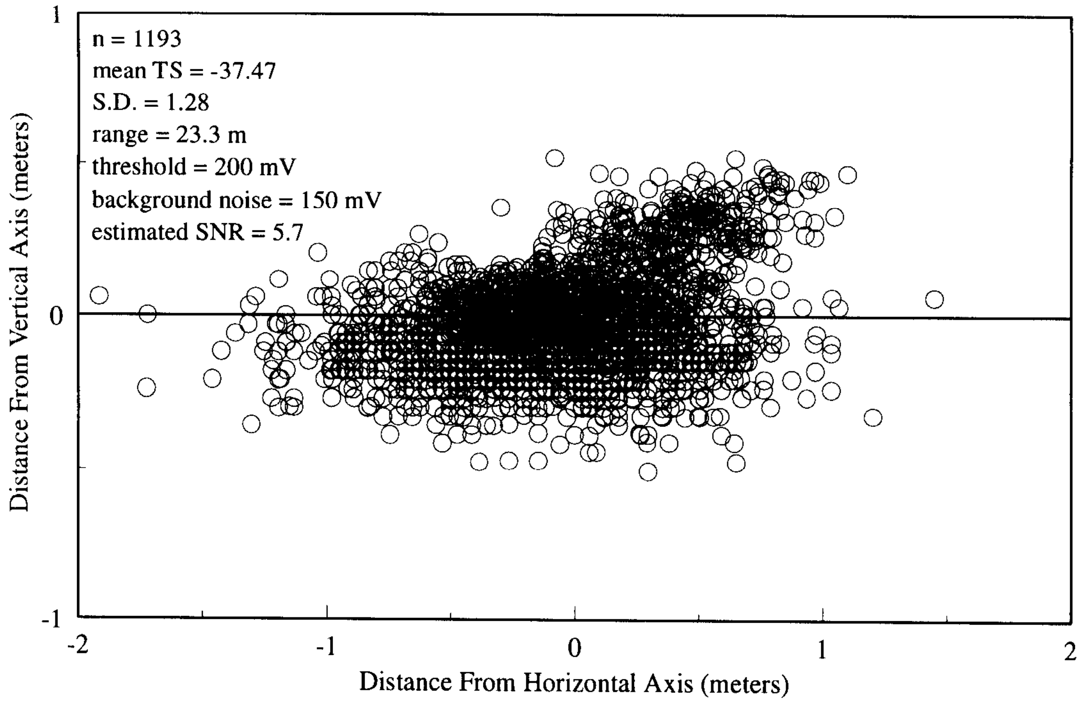
We compared the performance of the two systems with regard to ease and accuracy of calibration, precision of target strength measurements, target detection, and attenuation due to absorption.

Calibration

The split-beam system had two clear logistical advantages over the dual-beam system during *in situ* calibration checks. First, the split-beam system had a higher signal-noise ratio (SNR), which allowed the target to be located more easily. Second, the split-beam system was able to display the X-Y position of the target during data collection. This greatly facilitated aiming the transducer so that the target was on-axis (Figure 3).

The split-beam system yielded more precise measurements of target strength on the standard sphere than did the dual-beam system. *In situ* calibration data were collected several times during the 1994 season, using the same 38.1 mm diameter tungsten carbide sphere. Data were collected with the dual-beam system on 4 June and 11 July, and the split-beam system on 9 June and 11 July. During both the June and July calibration checks, the split-beam measurements were 4-5 times less variable than the dual-beam measurements (Figures 4 and 5). Traynor and Ehrenberg (1990) also found that beam pattern and target strength measurements of a standard sphere collected using the dual-beam technique were more variable than those derived using the split-beam technique. The difference in target strength variability between systems may also be partly due to the lower frequency of the split-beam sonar and the older technology of the dual-beam transducers. The 38.1 mm sphere may also not have been optimal for the 420 KHz system (MacClennan and Simmonds 1992).

June and July measurements were within 1 dB of each other for each system (Figures 4 and 5). The split-beam *in-situ* results were also within 1 dB of the results (-38.3 dB) of a preseason calibration check by the manufacturer in Seattle.



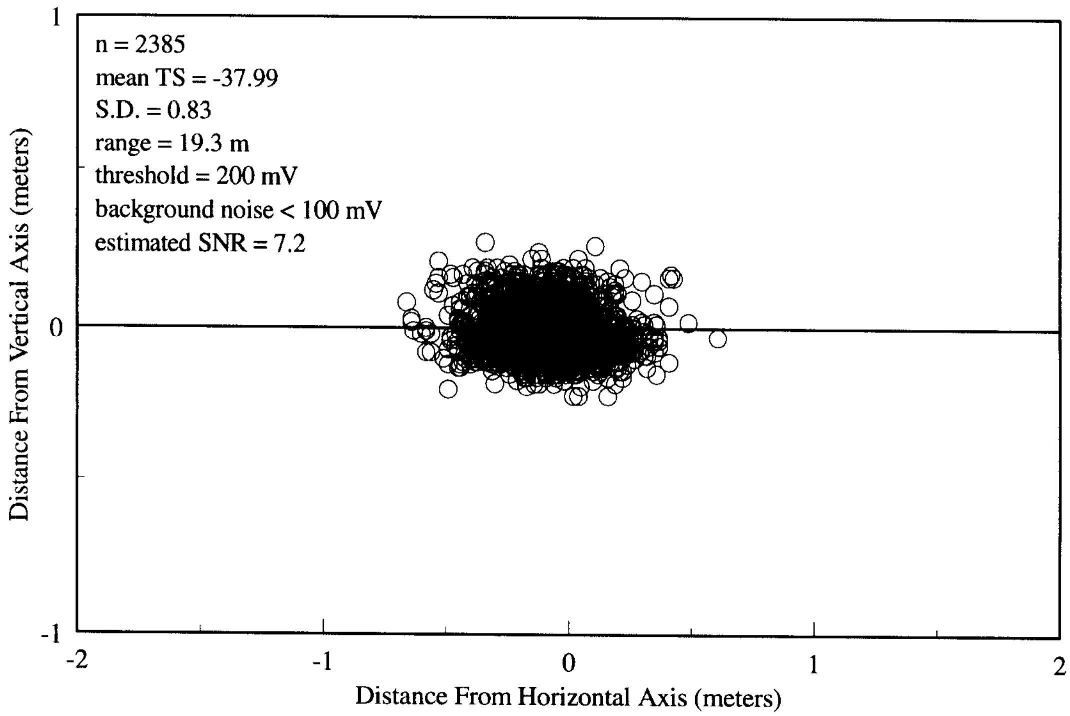


Figure 3.-Horizontal and vertical position of a 38.1 mm tungsten carbide target sphere in the acoustic beam during *in situ* calibrations on 9 June (top) and on 11 July (bottom).

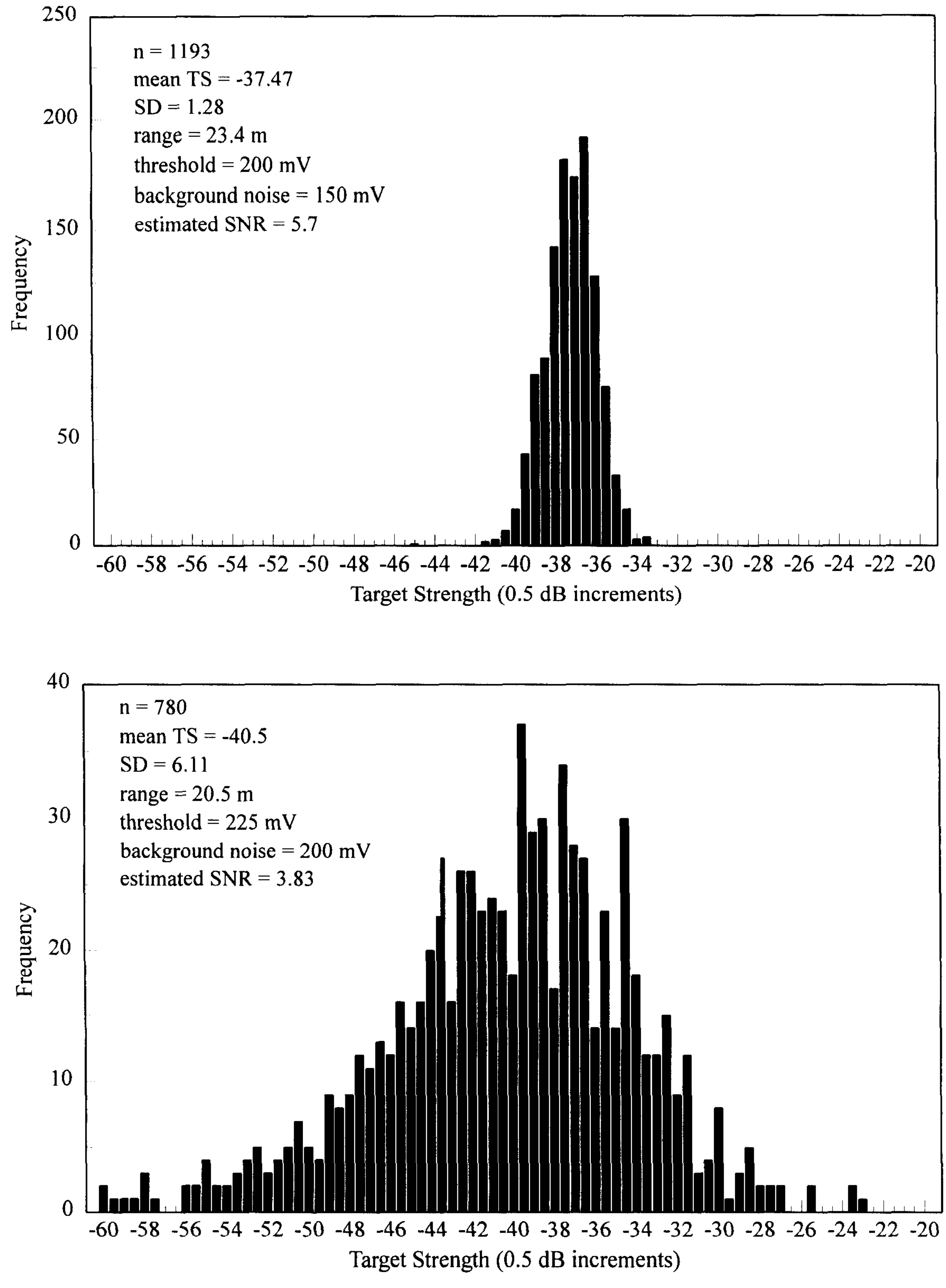
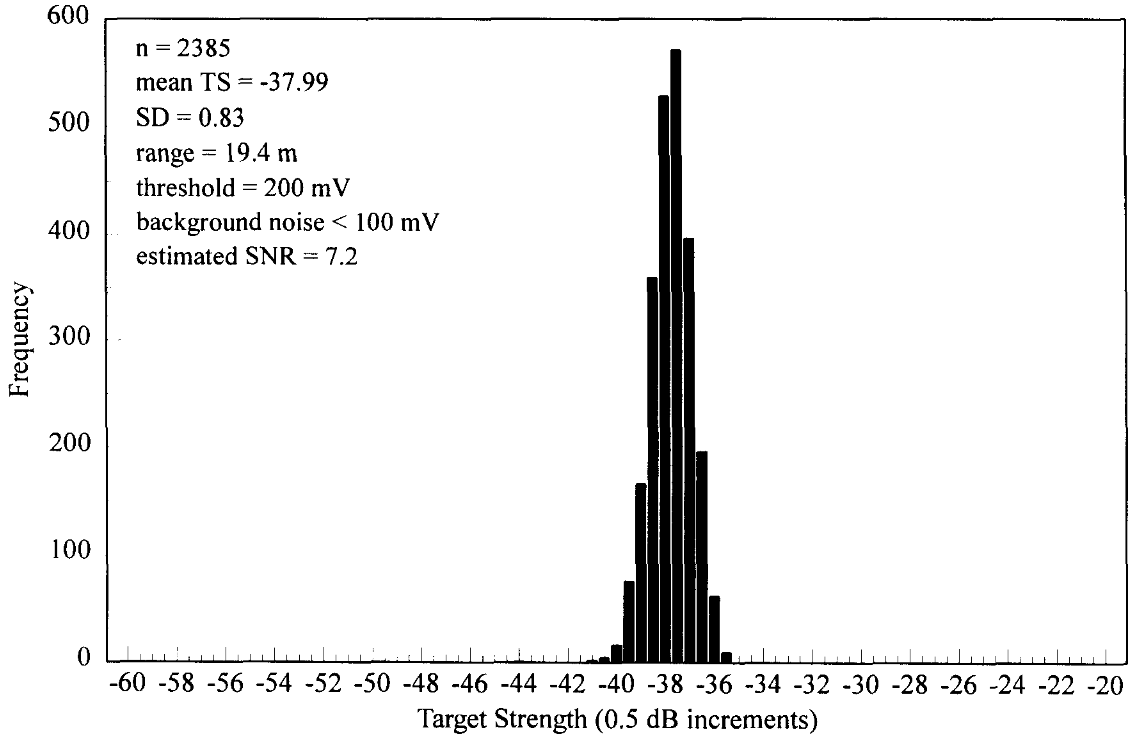


Figure 4.-Target strength frequency distributions for a 38.1 mm tungsten carbide target measured on 9 June with split-beam sonar (top) and on 4 June by dual-beam sonar (bottom).



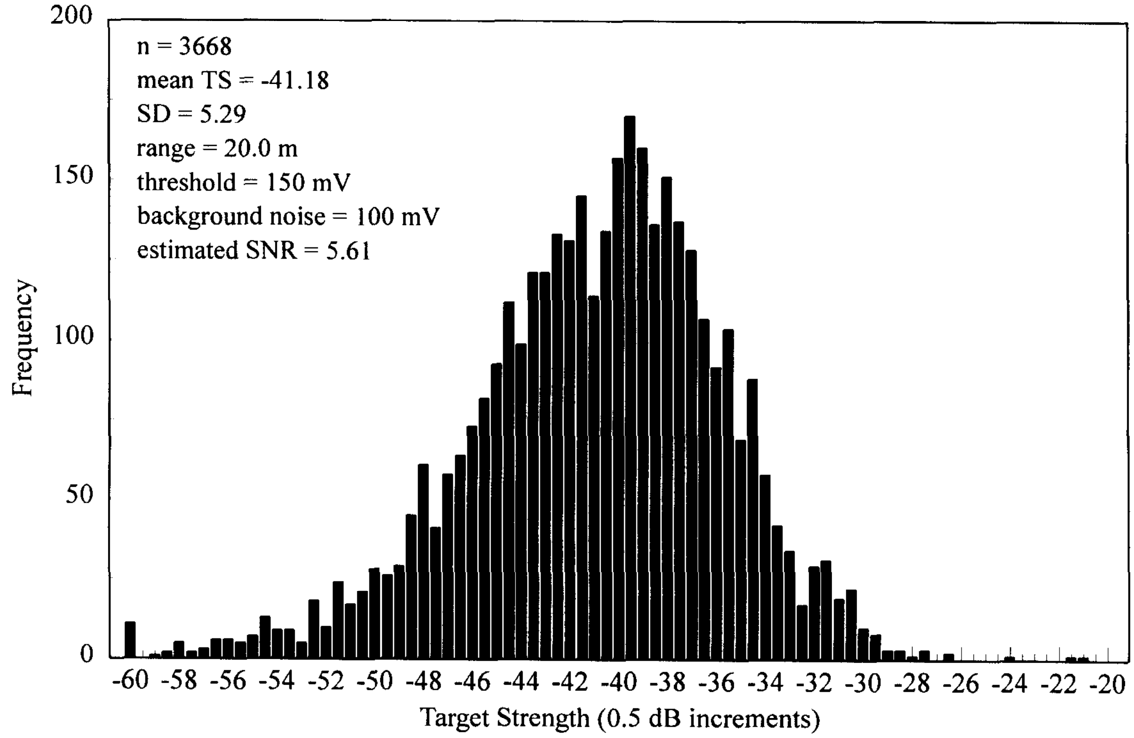


Figure 5.-Target strength frequency distributions for a 38.1 mm tungsten carbide target measured simultaneously by split-beam sonar (top) and dual-beam sonar (bottom) on 11 July 1994.

The split-beam system measured the standard sphere approximately 3 dB larger (-38 dB) than the dual-beam system (-41 dB; Figure 4, Figure 5). Two factors may have contributed to this difference. First, laboratory measurements of system source level and gain may not have been accurate, especially for the 420 kHz dual-beam system. Past calibrations of this system have not always been consistent, being sensitive to changes in temperature and calibration method (Alan Wirtz, Precision Acoustic Systems, Seattle, personal communication). Second, standard sphere measurements are frequency dependent, and the frequency effect interacts with target diameter (MacLennan and Simmonds 1992). The two systems, operating at different frequencies, would not be expected to measure the standard sphere exactly the same.

Target Strength Measurements

For fish ensonified by both systems, mean target strength as measured by split-beam sonar was correlated with mean target strength measured by dual-beam sonar ($r = 0.45$, $n = 145$, $P < 0.0001$). The split-beam sonar estimated target strength more precisely than did the dual-beam sonar (Wilcoxon signed-rank test on within-target standard deviations, $n = 145$, $P < 0.001$). Within-target standard deviation of target strength decreased with range for dual-beam sonar ($F = 8.35$; df = 1, 143; $P = 0.005$) but not for split-beam sonar ($F = 0.37$; df = 1, 143; $P = 0.544$; Figure 6).

Mean target strength did not differ between sonar types for fish ensonified by both (Wilcoxon signed rank test, $n = 145$, $P = 0.35$), however this result should be interpreted cautiously because of the differing *in situ* calibration results between the two systems and the differing thresholds used to process the data (see above).

Target Detection

The dual- and split-beam systems showed good agreement with regard to target detection. A total of 222 targets was detected by one system or the other. Of these, split-beam sonar detected 217 fish, or 98% of the total, and dual-beam sonar detected 214 fish, or 96% of the total (Table 6). The split-beam system detected slightly more echoes per target ($\bar{x} = 35.5$) than did the dual-beam system ($\bar{x} = 31.2$; Wilcoxon signed rank test, $n = 145$, $P = 0.032$). This difference would have been greater still, had the split-beam threshold not been artificially raised to be equivalent to the dual-beam threshold.

Attenuation Due to Absorption

Sound energy attenuates (declines) exponentially with distance due to absorption. The rate of attenuation is proportional to the square of the frequency (MacLennan and Simmonds 1992), so 420 kilohertz (kHz) sound should attenuate >4 times faster than 200 kHz sound. Among targets ensonified by both systems, mean target strength increased as a function of range for both 200 kHz and 420 kHz sonar ($F = 27.84$; df = 1, 326; $P < 0.001$); although the rate of increase did not differ between them ($F = 0.23$; df = 1, 326; $P = 0.633$; Figure 7). The increase in target strength with range may be due to an increase in size of fish with distance from shore or the measurement bias against smaller targets at greater ranges (Traynor *In press*). That is, as SNR decreases and variability increases with range, more of the smaller echoes are censored by the noise threshold. The equal rates of target strength increase were unexpected given the relationship between absorption rates and frequency. It is possible that the above measurement bias is greater for the dual-beam system and compensates for the increased absorption rate. This would explain the decrease in standard deviation over range exhibited only by the dual-beam system (Figure 6).

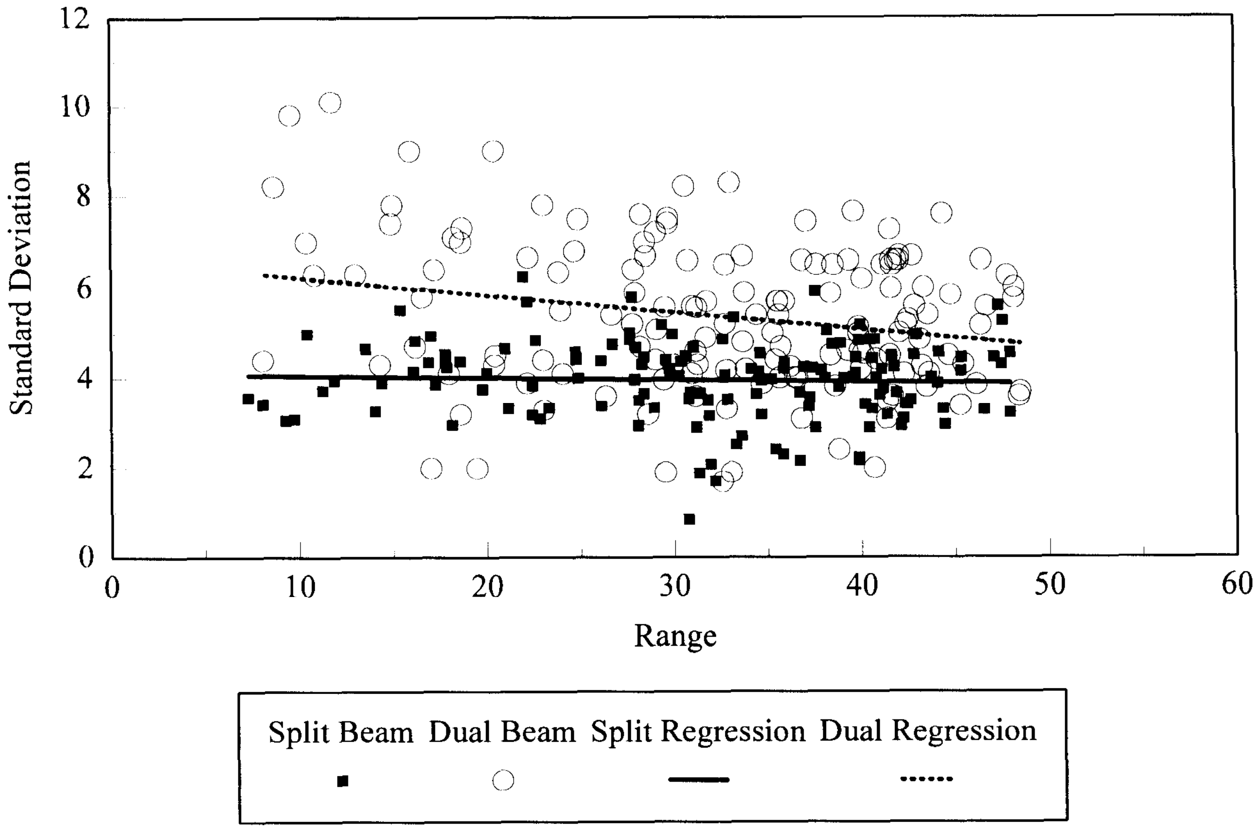


Figure 6.-Within-fish standard deviation of target strength versus range for dual- and split-beam sonar.

Table 6.-Number of fish detected by either dual-beam or split-beam sonar systems, Kenai River chinook salmon sonar site, 1-5 July 1995.

	Detected by split-beam system	Not detected by split-beam system	Total detected by at least one system
Detected by dual-beam system	209	5	214
Not detected by dual-beam system	8	(0)[a]	8
Total detected by at least one system	217	5	222

[a] Actual number of fish not detected by either system is unknown.

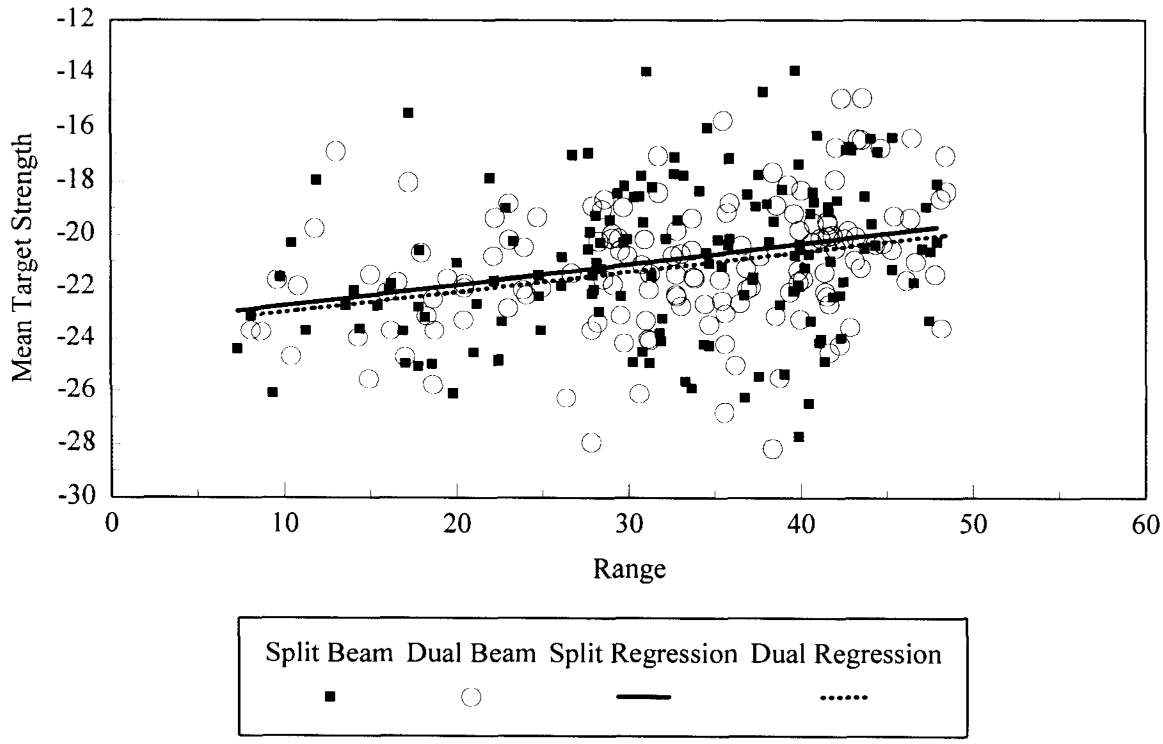


Figure 7.-Target strength versus range for dual- and split-beam sonar.

Conclusions

In addition to its ability to determine fish spatial distribution and direction of travel, the split-beam system proved to have several advantages over the dual-beam system for our application. It was easier to calibrate *in situ* and gave more precise standard sphere measurements. The split-beam system also provided more precise estimates of fish target strength.

The split-beam system did not, however, appear to have any distinct advantages over the dual-beam system with regard to detecting and tracking fish when both systems were well-aimed and operating concurrently. Nor was there a detectable difference in how target strength varied with range between the 200 kHz split-beam system and the 420 kHz dual-beam system. At present, we cannot state whether the increase in target strength with range is due to measurement bias or actual change in mean fish target strength. Attenuation is probably not a major factor with either frequency for this application. However, additional data should be collected with a standard sphere at varied ranges to confirm this.

OBJECTIVE 2: SPATIAL DISTRIBUTION OF TARGETS

Knowledge of the spatial distribution of fish is desirable for determining appropriate transducer beam dimensions and for developing strategies for ensonifying a specific area. This is particularly important at the present (mile 8) site, where tidally-induced changes in water level have been shown to affect fish distribution. During the 1986 season cross-river transects were conducted with downward-looking sonar to map the vertical distribution of fish at the current sonar site at four tide stages: high slack, low slack, flood tide, and falling tide. Fish were strongly bottom-oriented, especially at low tide (Eggers et al. 1995). However, there was some question as to whether the results were biased because of inadequate sample volume near the surface or because of fish avoiding the transect boat.

Analytical Methods

Split-beam data collected at high (-33.8 dB) and low thresholds (-40.8 to -38.9 dB) were analyzed for spatial distribution of targets. Mean position in the X (up- and downstream), Y (up and down), and Z (range, or distance from transducer) dimensions was calculated for each target.

Results

Fish were strongly oriented to the bottom of the acoustic beam during both runs, although vertical distribution did vary somewhat by direction of travel, tide stage, and season. In the high-threshold data set, relatively more targets occurred above the acoustic axis among downstream targets than among upstream targets ($\chi^2 = 25.4$, df = 1, $P < 0.001$; Figure 8, Figure 9). There were more upstream targets above the axis on the rising tide than during falling or low tides ($\chi^2 = 26.2$, df = 2, $P < 0.001$) during the early run, but not the late run (Figure 10, Figure 11). Finally, with the low-threshold data set, there were more upstream targets above the axis on 18 July than on 4 July ($\chi^2 = 26.4$, df = 1, $P < 0.001$; Figure 12, Figure 13).

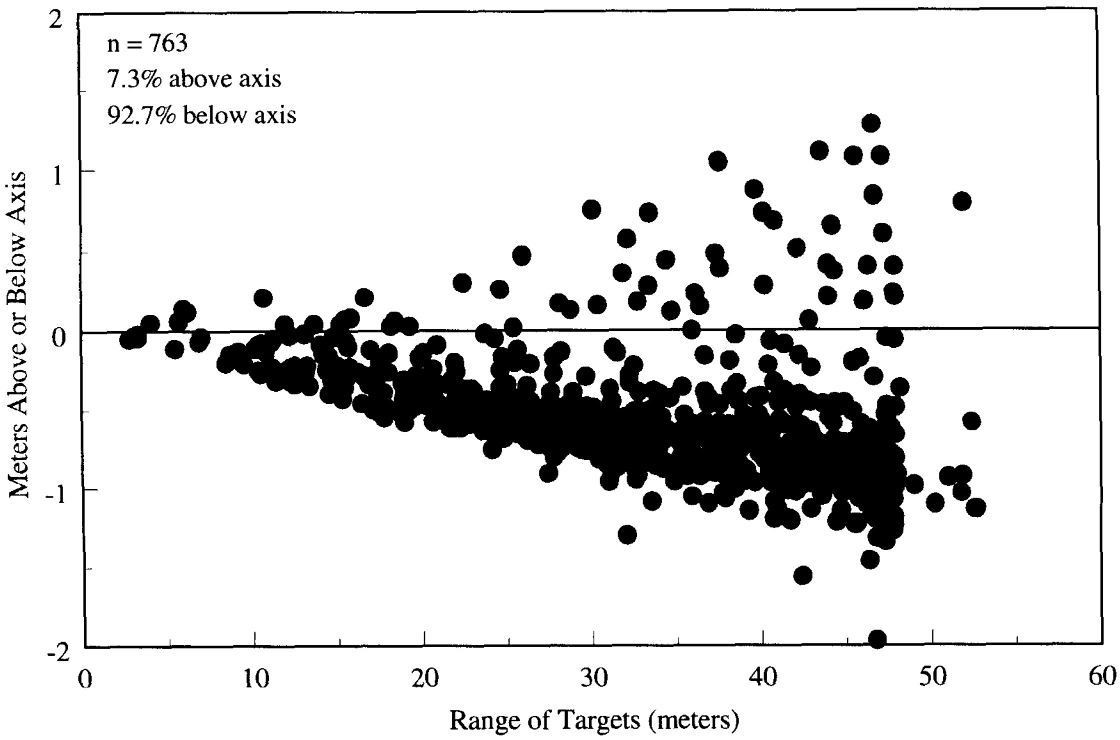
There were relatively more targets ($\chi^2 = 34.2$, df = 1, $P < 0.001$) within 15 m of the transducer during the late run (15%) than during the early run (7%) for the high-threshold data set (Figure 14). Most nearshore fish in the late-run high-threshold data occurred during the rising tide (Figure 15).

Range distribution also differed between data collected 4 and 18 July at low threshold ($\chi^2 = 103.3$, df = 1, $P < 0.001$). A much larger proportion of targets was close to shore (38.5% at < 15 m range) on 18 July when many sockeye were present, than on 4 July when few sockeye were present (9.2%; Figure 16). High rates of passage near shore persisted throughout all tide stages on 18 July.

Conclusions

Upstream-traveling targets were strongly bottom-oriented in the beam, indicating the importance of maintaining a precise aim along a straight bottom profile. The potential for missing bottom-oriented fish swimming under the beam is minimized by the fact that the river bottom at the mile 8 site is composed of acoustically lossy mud which allows a very low grazing angle as the beam is aimed parallel to the bottom. The result is that the acoustic beam effectively ensonifies the near-bottom region very well. Additionally, the location of the primary acoustic scatterer (the swim bladder) is located just below the backbone and consequently will be at least several inches above the river bottom.

Given the declining density of targets with distance from the bottom during all tide stages, it seems unlikely that many upstream-traveling fish escape detection by swimming over the beam. Downstream targets, however, were more evenly distributed throughout the beam, indicating that a portion of downstream migrants were probably undetected above the beam. At present, it is unclear what proportion of downstream targets are fish rather than debris (see following section Direction of Travel).



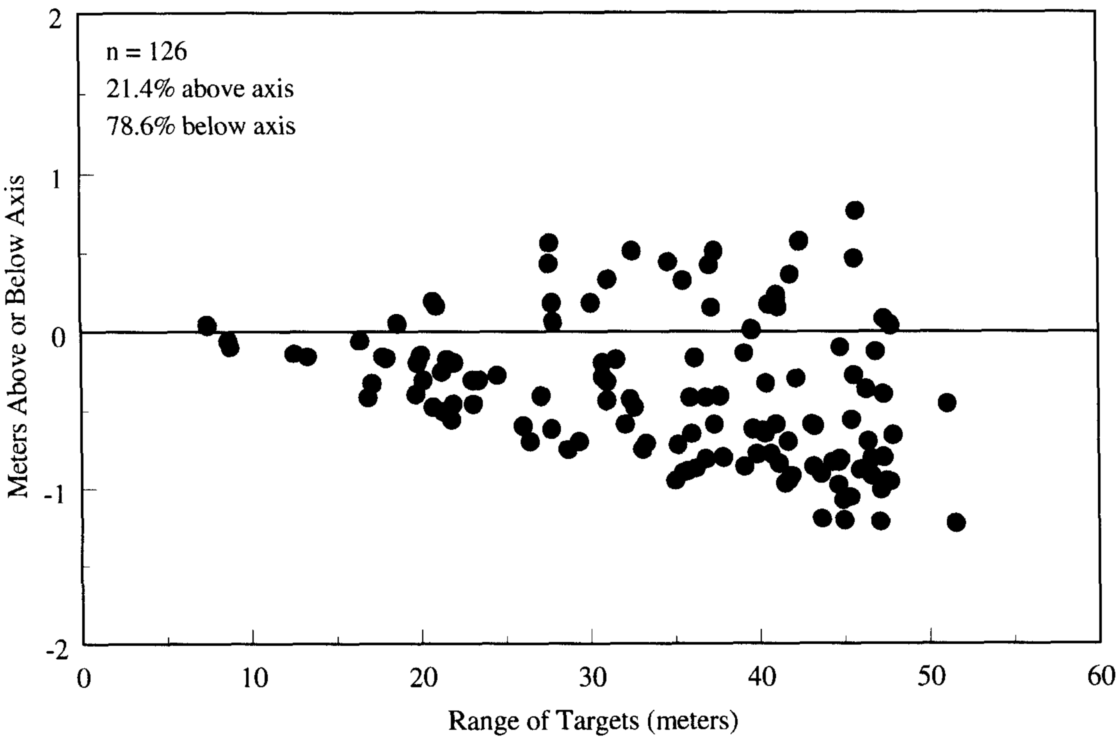
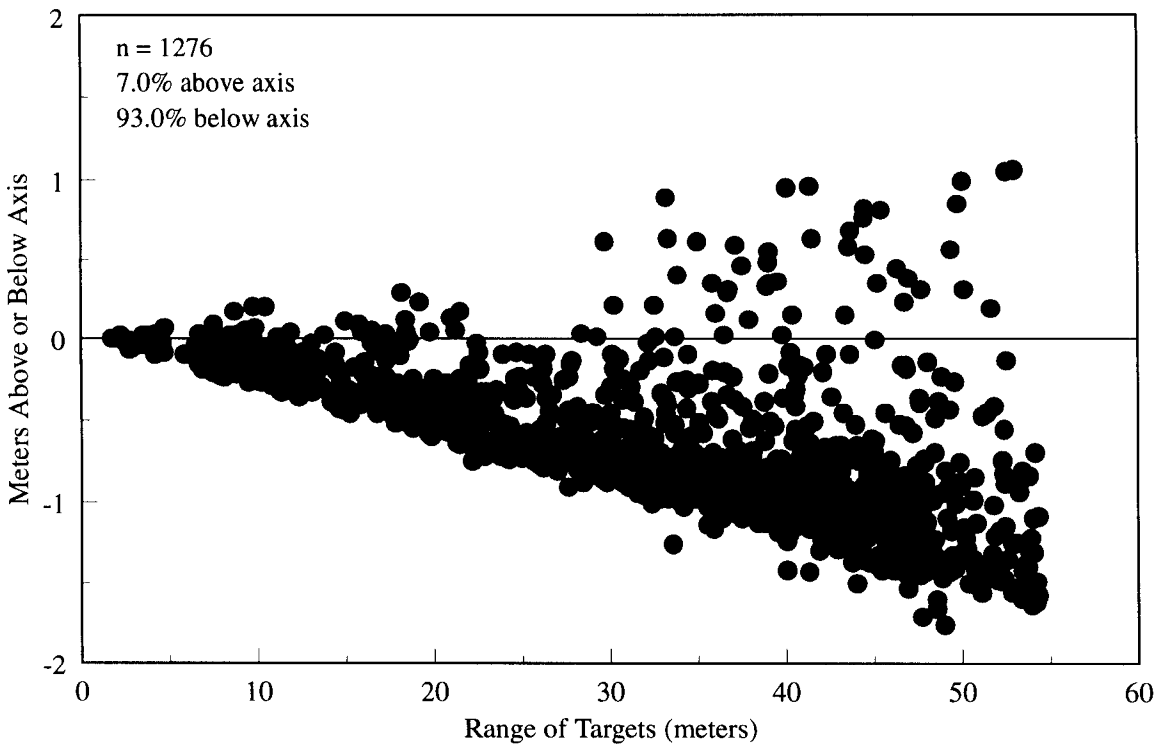


Figure 8.-Mean vertical position versus mean range for upstream fish (top) and downstream fish (bottom) for the early-run, high-threshold data set.



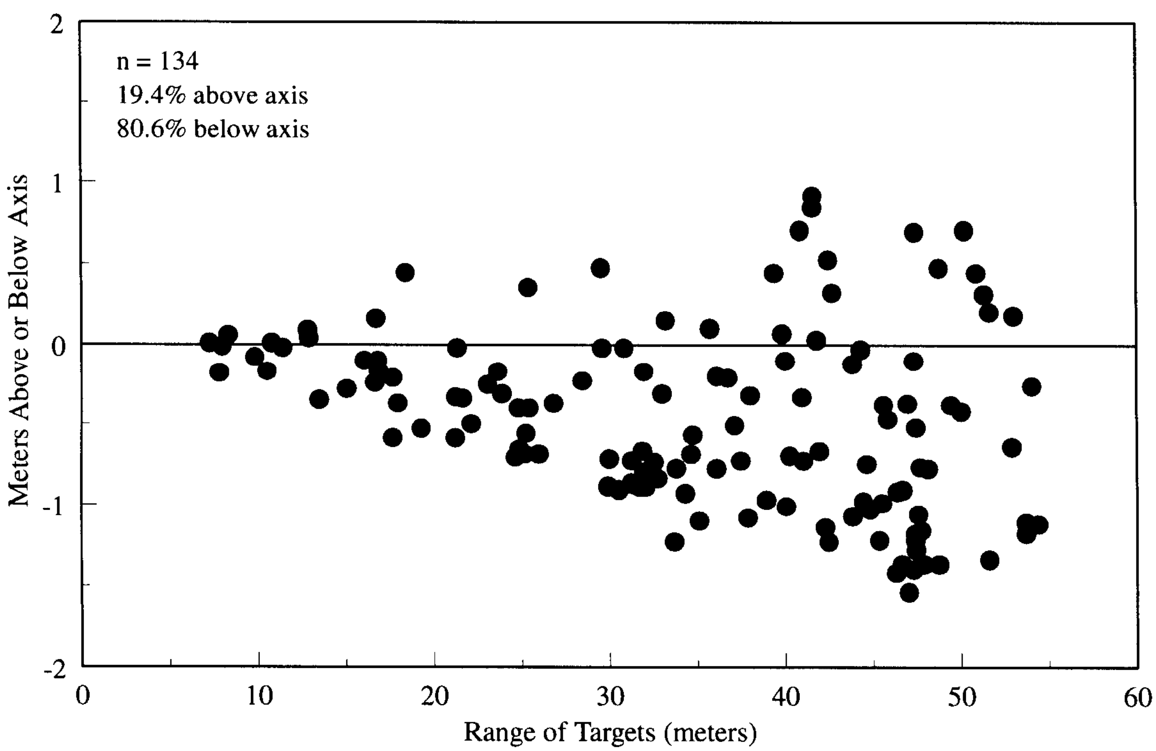


Figure 9.-Mean vertical position versus mean range for upstream fish (top) and downstream fish (bottom) for the late-run, high-threshold data set.

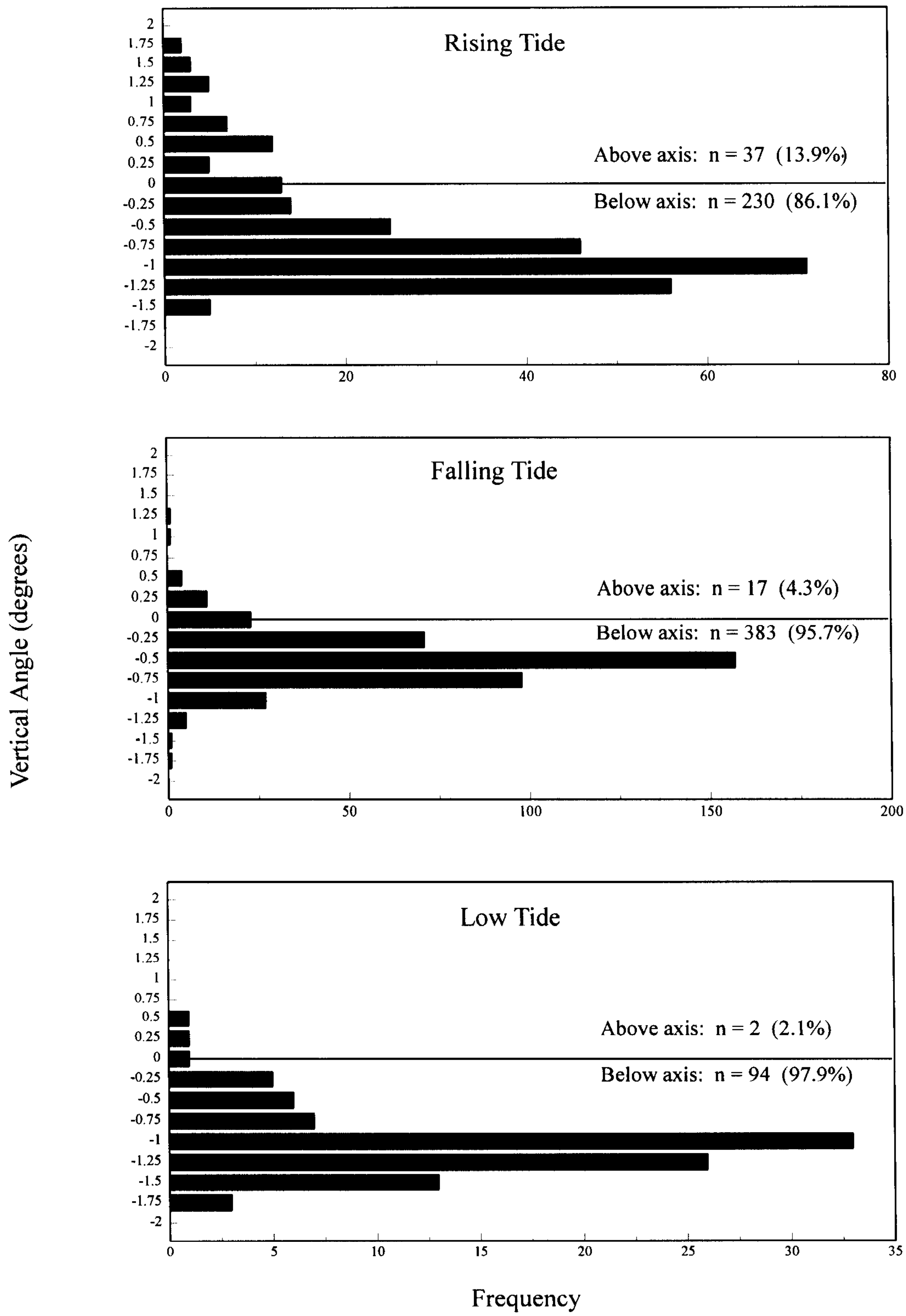


Figure 10.-Vertical distribution (surface = 1. 75°, bottom = -1.75°) of upstream traveling, early-run fish during the rising, falling, and low tide stages.

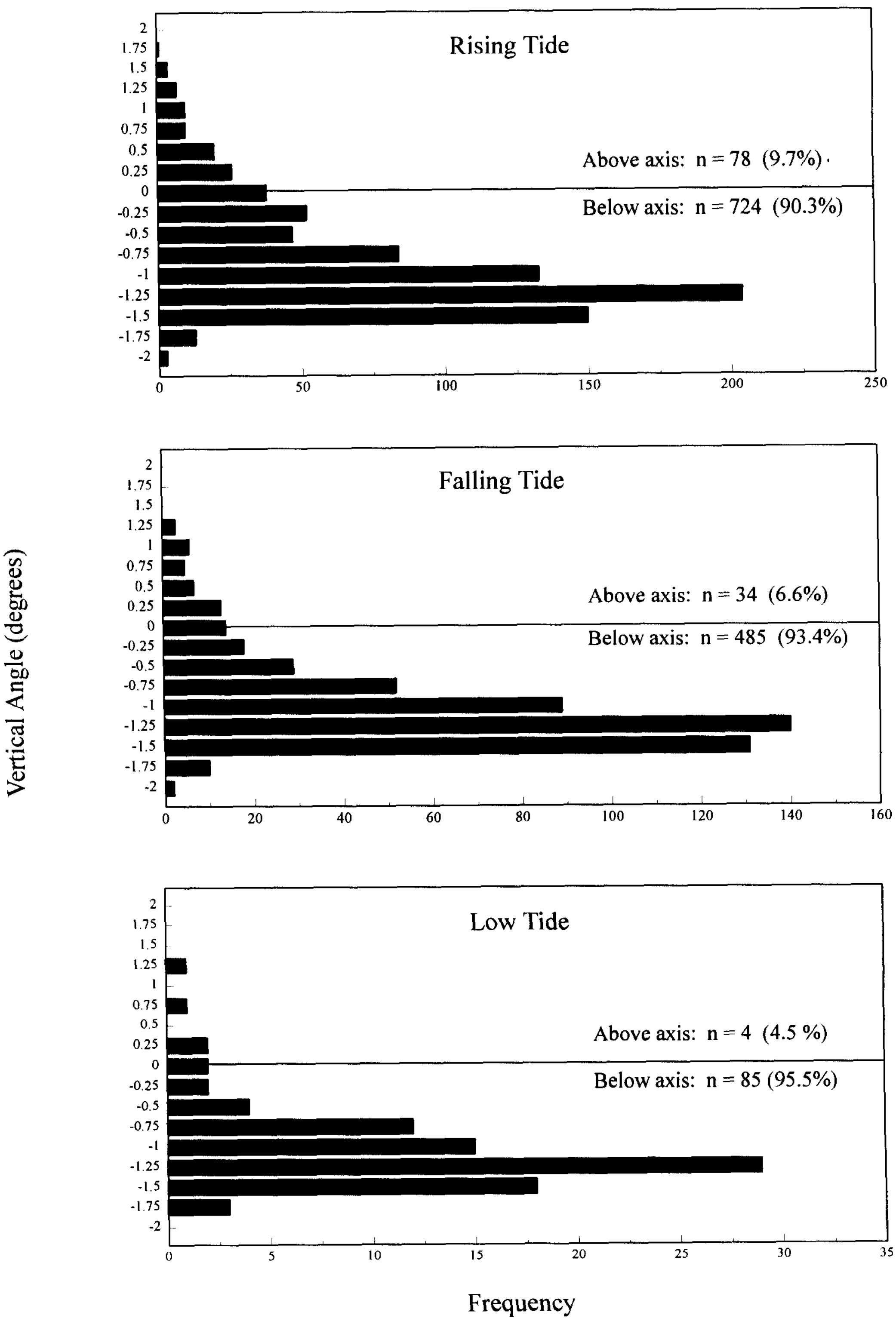


Figure 11.-Vertical distribution (surface = 1. 75°, bottom = -1.75°) of upstream traveling, late-run fish during the rising, falling, and low tide stages.

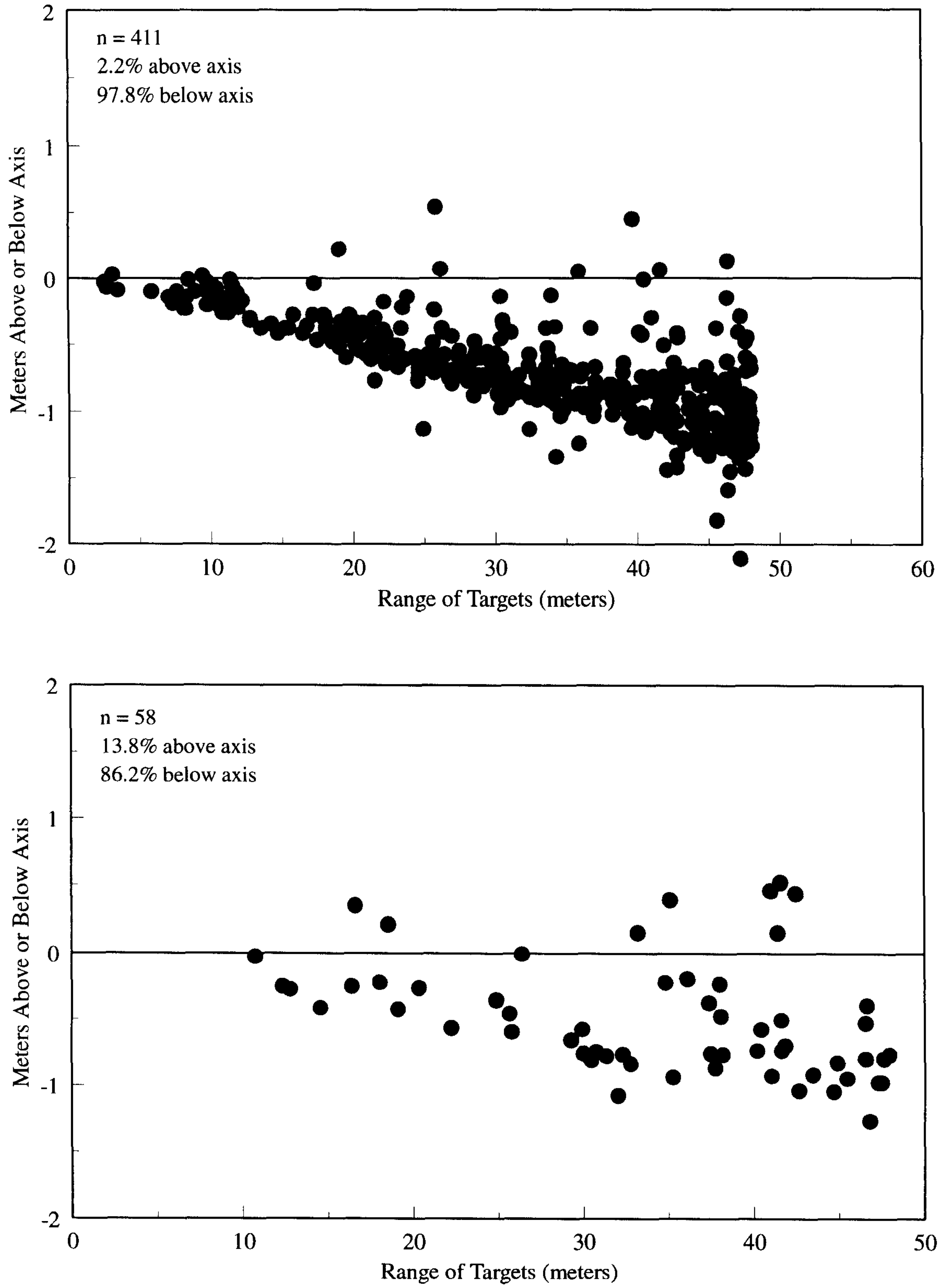


Figure 12.-Mean vertical position versus mean range for upstream (top) and downstream (bottom) fish in low-threshold data collected on 4 July 1994.

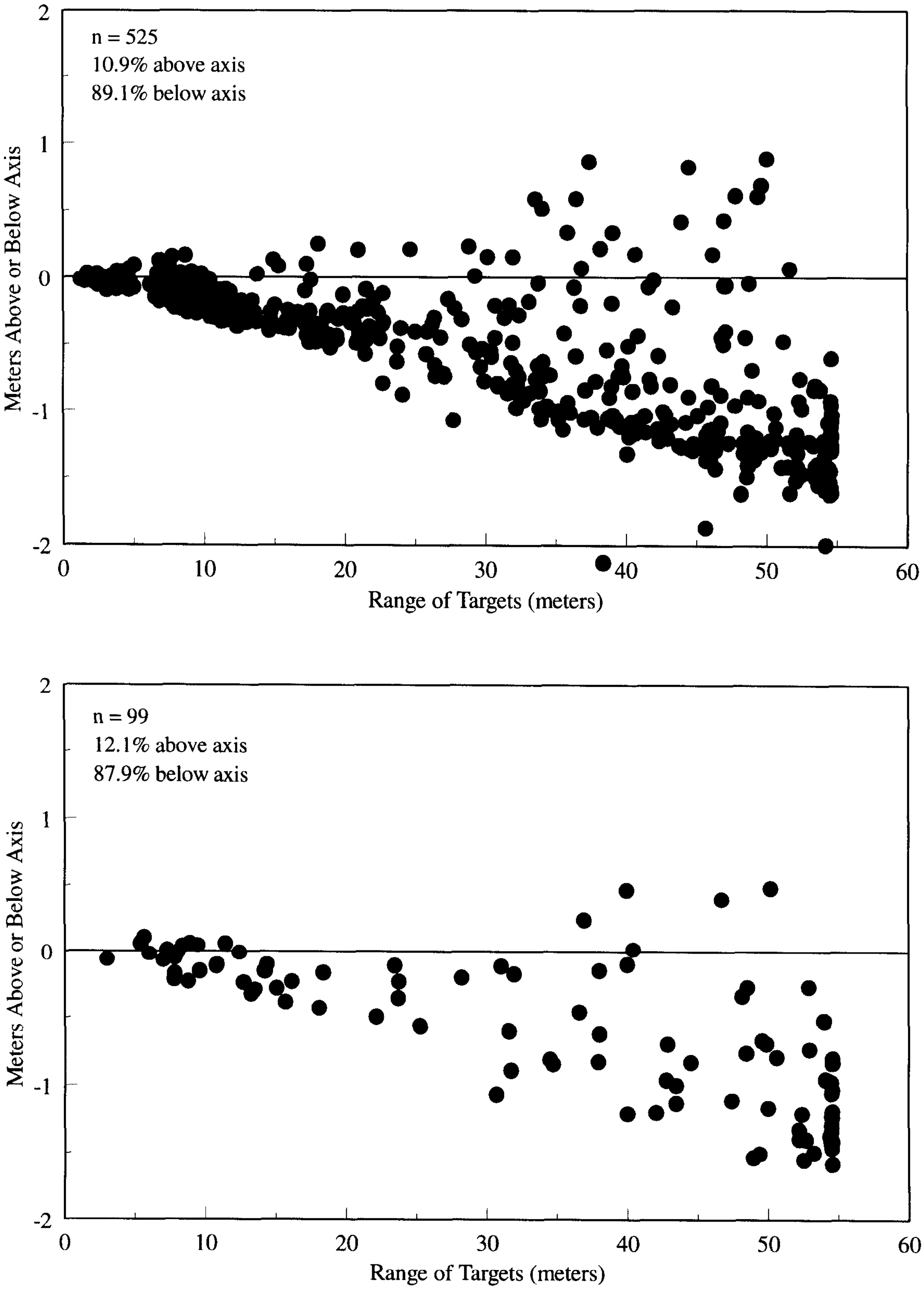


Figure 13.-Mean vertical position versus mean range for upstream (top) and downstream (bottom) fish in low-threshold data collected on 18 July 1994.

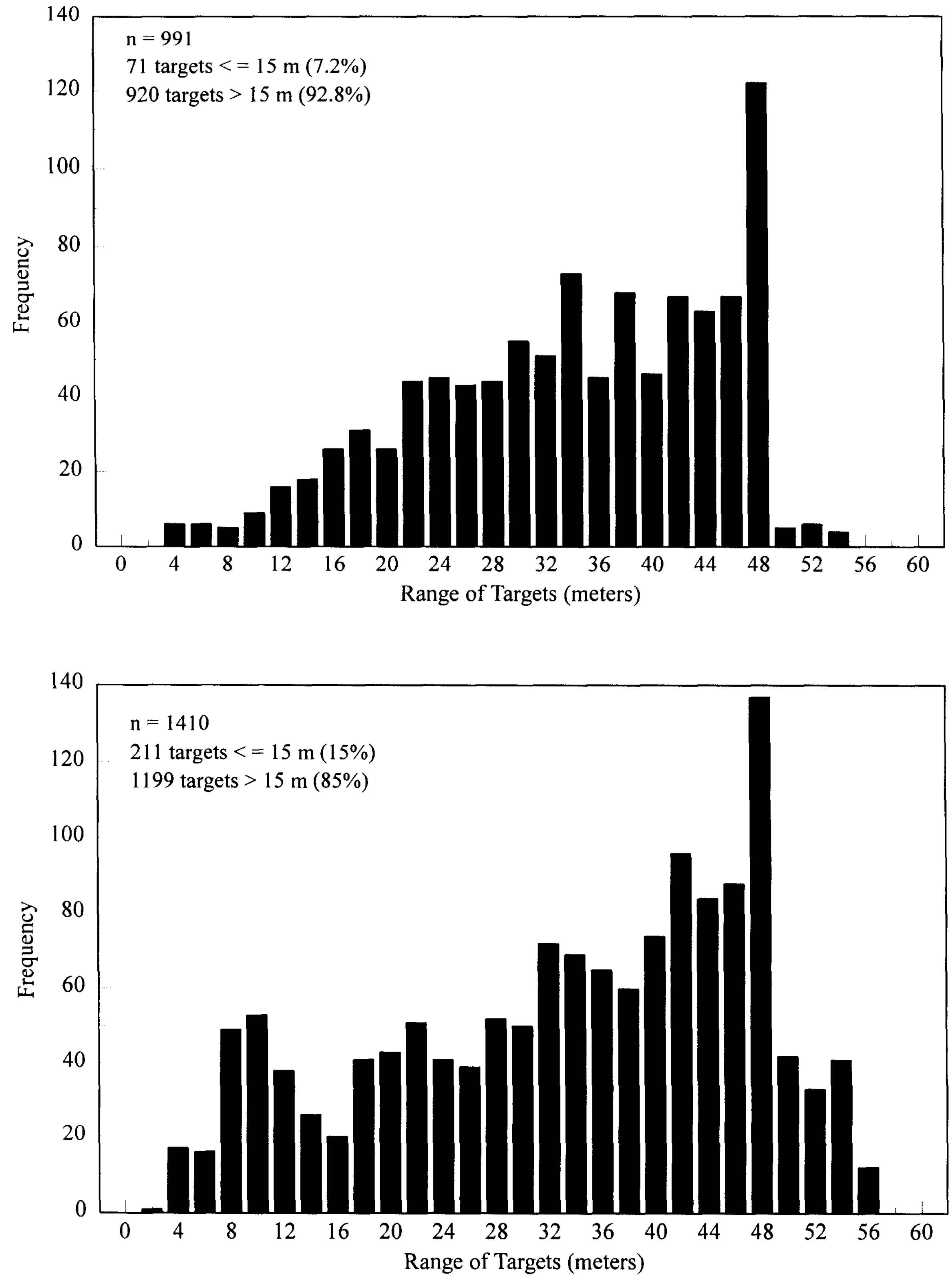
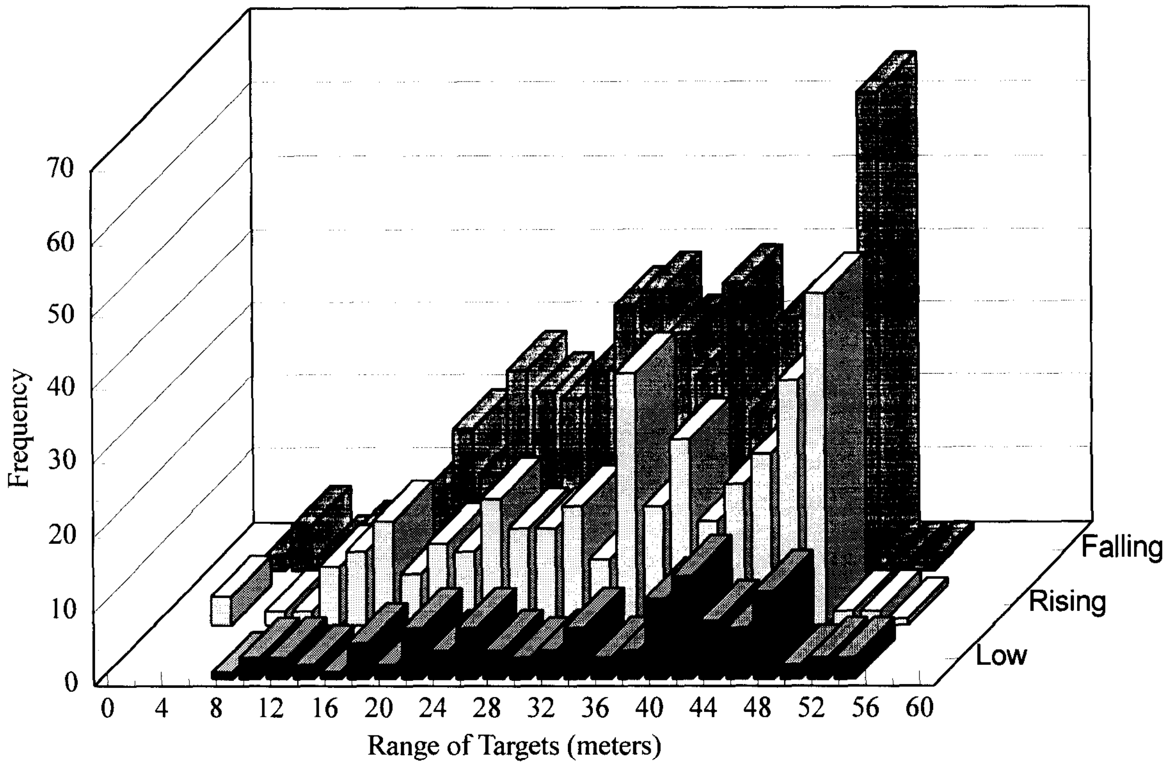


Figure 14.-Frequency distribution of range for all targets in high-threshold data collected during the early (top) and late (bottom) runs.



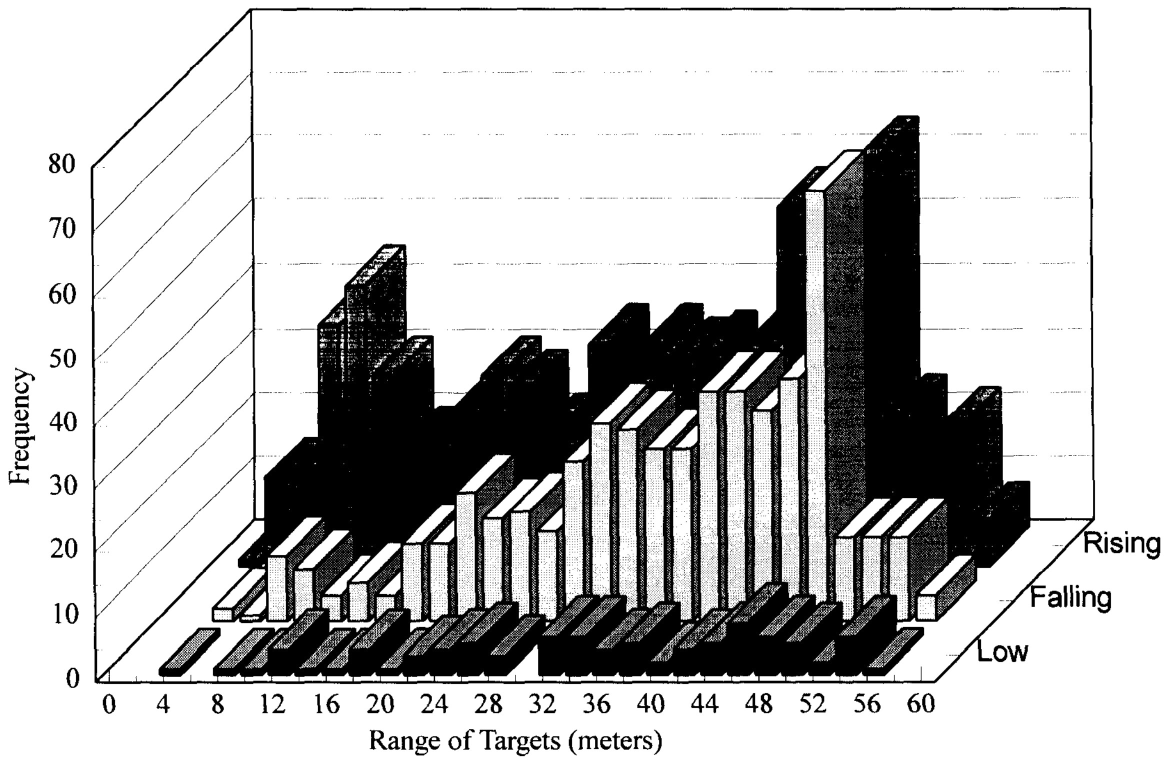


Figure 15.-Frequency distribution of range for all targets in high-threshold data collected during the early run (top) and late run (bottom), by tide stage.

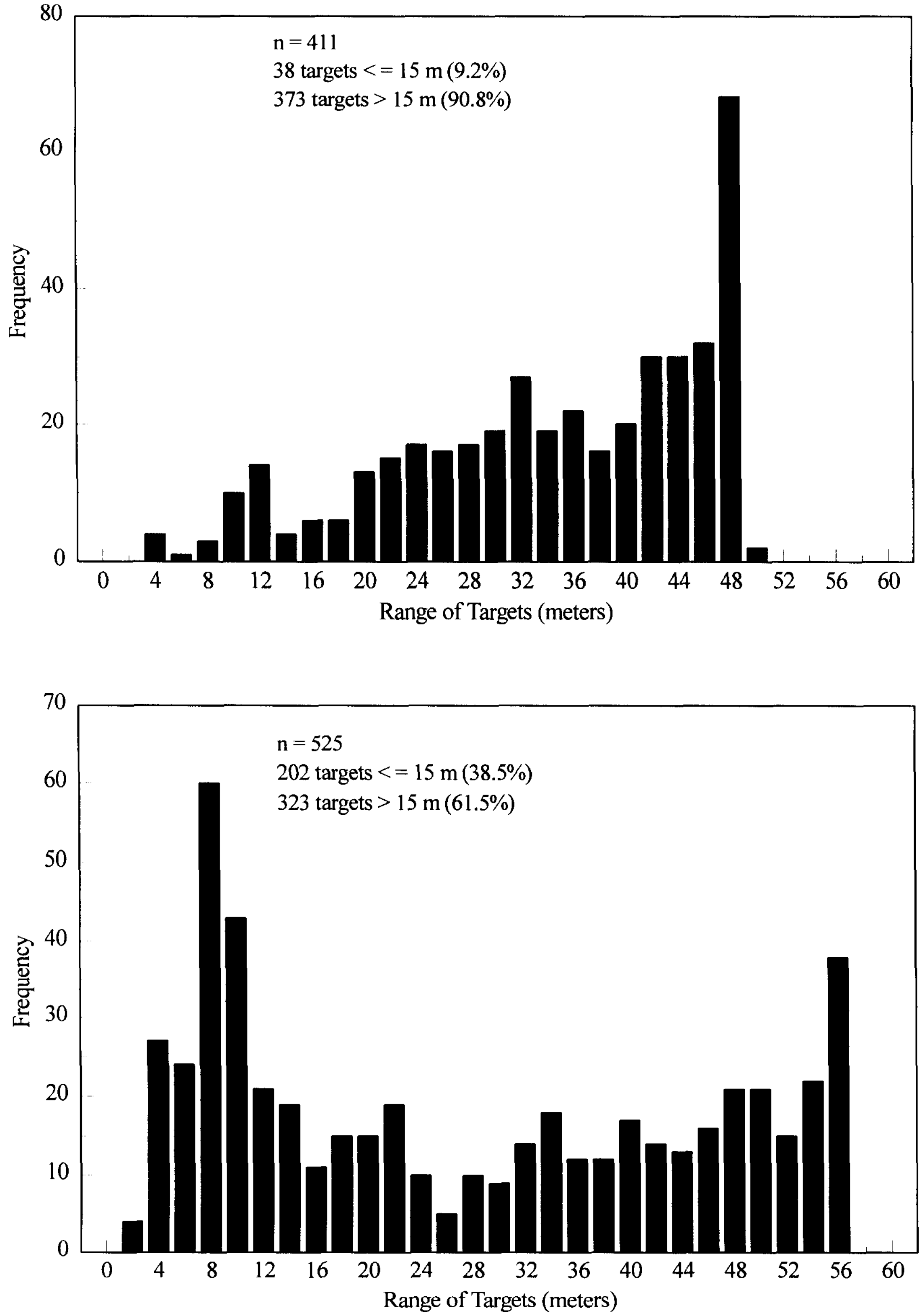


Figure 16.-Frequency distribution of range for all targets in low-threshold data collected on 4 July (top) and on 18 July (bottom).

The proportion of targets nearshore increased during times of high sockeye passage, which is consistent with evidence from other sites that most sockeye salmon migrate close to shore (e.g., King and Tarbox 1989a, 1989b, 1991).

The above analyses do not directly address the question of how many chinook salmon swim behind the transducer. However, the majority of targets were near the middle of the river when sockeye were few in number, suggesting that chinook salmon tend to travel offshore in the deeper sections of the river. This is consistent with the observed preference of Kenai River sport fisherman for fishing in deep holes and near mid-channel. Personnel involved with netting and tagging chinook salmon have also had higher capture success when fishing the middle portions of the river (Mary King, Alaska Department of Fish and Game, Soldotna, personal communication).

OBJECTIVE 3: DIRECTION OF TRAVEL

The dual-beam system, as it has been traditionally deployed, is incapable of determining whether a fish passing the sonar is traveling upstream or downstream. Fish traveling downstream have therefore been included in dual-beam chinook salmon passage estimates, biasing the results to some degree. The magnitude of this bias has been a matter of perennial concern for the project, especially since the sonar site is located relatively near the river mouth and has current reversal during extreme high tides.

Previous Studies

Two previous experiments have been conducted to determine direction of travel of migrating chinook salmon. The first experiment was conducted in 1985 and used angle of passage through the acoustic beam to determine direction of travel for targets. This study estimated a downstream component of 3.5% of all tracked targets. However, the results were inconclusive due to the large number of targets (>50%) for which direction of travel could not be determined (Eggers et al. 1995).

Bendock and Alexandersdottir (1990) observed a large proportion of radio-tagged chinook moving downstream past the sonar (39%), so a second experiment was implemented to provide an independent estimate of downstream fish. This study, conducted in 1990, used two side-by-side mounted transducers to track fish as they moved first through one beam, through both beams, and finally through the second beam. This method appeared to be more reliable than the first and yielded an estimate of 3% downstream fish. Eggers et al. (1995) showed that the number of downstream targets was similar to the fraction of tagged chinook salmon (caught with sport gear and radio tagged) that migrated below the sonar site multiplied by the total number of released chinook salmon from the sport fishery. This suggested that the primary source of downstream targets might be chinook salmon caught and then released by sport anglers.

ANALYTICAL METHODS

A target was classified as upstream if its ending (X-axis) position was located upriver from its starting position, and downstream if its ending position was downriver from its starting position.

Results

Estimated proportions of downstream targets ranged from a low of 9.5% for the late run, high-threshold data, to a high of 15.7% for the low-threshold data with many sockeye present

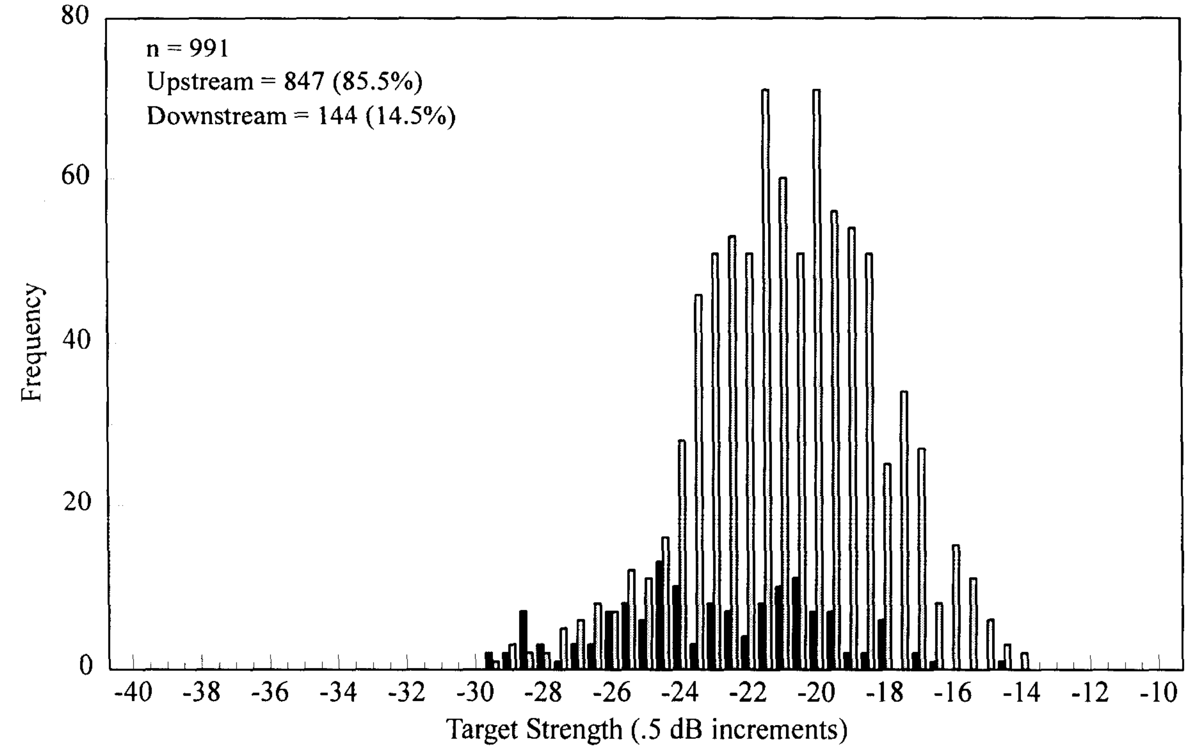
(Table 7). However, downstream targets had different target strength (TS) distributions than did upstream fish. Mean TS was less for downstream targets than for upstream targets for all four data sets (Z tests, $P < 0.001$), with the differences ranging from 2.1 to 2.8 dB (Table 7, Table 8). Between-target standard deviation of TS was always larger, and the within-target standard deviation was always smaller, for downstream targets than for upstream targets (Table 7, Table 8). Downstream target-strength distributions appeared to be multimodal, with the upper mode approximately corresponding to the mode of the upstream target strength distribution (Figure 17).

Table 7.-Number and target strength (TS) characteristics of downstream targets in four data sets collected with split-beam sonar at the Kenai River chinook salmon sonar site, 1994.

Data Set	Total # of targets	Total # Downstream	Percent Downstream	TS Mean	Between-target standard deviation	Within-target standard deviation
High threshold						
Early Run	991	144	14.5%	-23.28	3.14	3.30
Late Run	1410	134	9.5%	-23.93	3.70	3.25
Low threshold						
4 July	469	58	12.4%	-25.84	4.31	3.32
18 July	624	99	15.7%	-28.10	4.16	3.21

Table 8.-Number and target strength (TS) characteristics of upstream targets in four data sets collected with split-beam sonar at the Kenai River chinook salmon sonar site, 1994.

Data Set	Total # of targets	Total # Upstream	Percent Upstream	TS Mean	Between-target standard deviation	Within-target standard deviation
High threshold						
Early Run	991	847	85.5%	-21.09	2.66	3.82
Late Run	1,410	1,276	90.5%	-21.87	2.97	3.88
Low threshold						
4 July	469	411	87.6%	-23.04	3.23	4.42
18 July	624	530	84.3%	-25.47	3.59	4.14



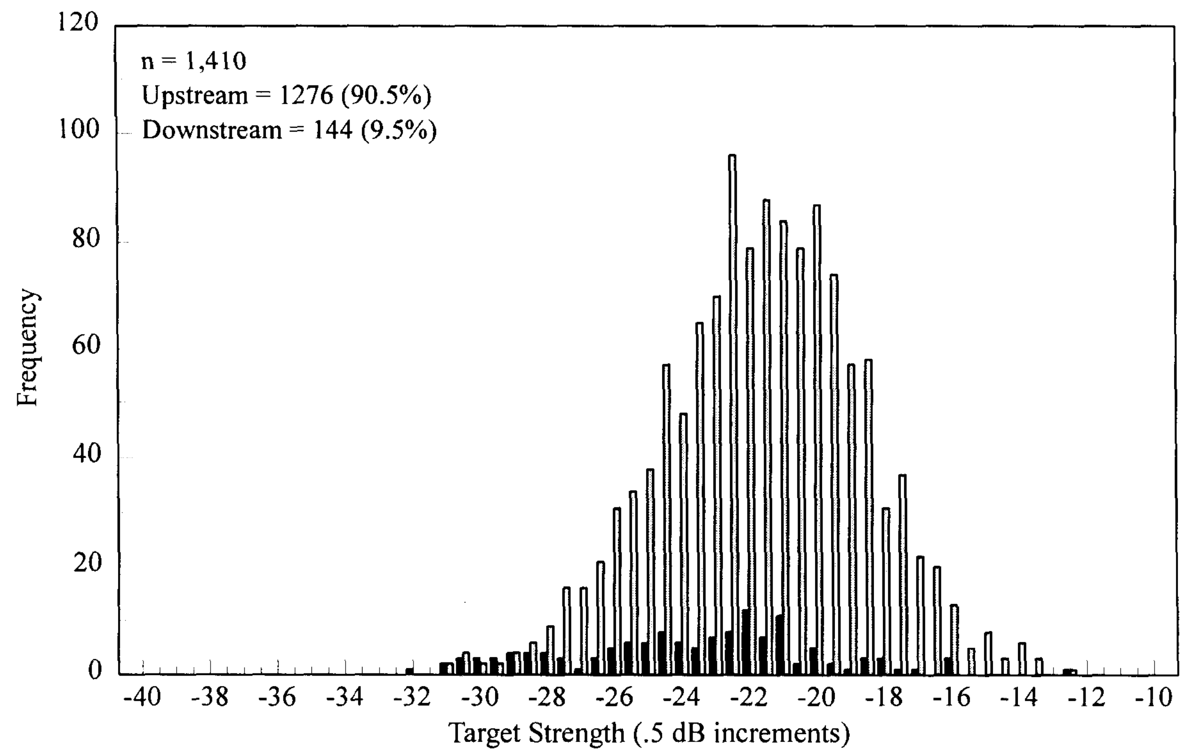


Figure 17.-Target strength distributions by direction of travel for high-threshold data collected during the early run (top) and late run (bottom).

Conclusions

The proportion of downstream targets estimated by split-beam sonar are too high to be explained by fish released from the sport fishery. During the 1994 early and late runs, it was estimated that anglers caught and released 2,001 and 4,151 chinook salmon, respectively (Steve Hammarstrom, Alaska Department of Fish and Game, Soldotna, personal communication). If approximately 39% of fish migrate downstream after release (Bendock and Alexandersdottir 1990), then about 780, or 4.2% of the early run, and 1,619, or 3.0% of the late run might pass downstream through the sonar. While similar to previous estimates of downstream passage, they are well below 1994 estimates from split-beam sonar.

The target strength data suggest that not all downstream targets were chinook salmon; they may include smaller fish or debris. Another possible explanation is that downstream migrating fish are transecting the beam at a different angle than upstream fish causing the observed difference in target strength distributions. At present, we have no means of estimating how many of the downstream targets are chinook salmon.

OBJECTIVE 4: SPECIES DISCRIMINATION USING TARGET STRENGTH

Previous Studies

Ehrenberg (1984) suggested the possibility of using target strength to discriminate between different sizes of salmon migrating upstream in rivers. Because side-aspect target strength is highly variable in a riverine setting, this approach would require large differences in size between species, as well as numerous measurements of target strength on each fish. Research with dual-beam sonar conducted in 1985 and 1986 concluded that target strength could be used to discriminate large chinook salmon from other salmon in the Kenai River (Paul Skvorc, Alaska Department of Fish and Game, Anchorage, personal communication). In brief, these studies found that mean target strength per fish had a bimodal distribution, with the two modes approximately 12 dB apart. The two modes were separated by a notch at -28.5 dB, and were thought to correspond to sockeye and chinook salmon. Therefore, since 1987 all fish with mean target strength less than -28 dB (to be conservative) have been excluded from chinook salmon counts.

However, there were early indications that the -28 dB threshold was not excluding all sockeye. During heavy sockeye runs there were sometimes numerous nearshore targets on the chart recordings which differed greatly in appearance from the usual targets. During the peak of a record sockeye run on 9-14 July 1989, a large number of nearshore targets appeared up to 10-15 m from the transducer (Figure 18, Figure 19). It became apparent that these were probably sockeye salmon, and many exceeded the -28 dB threshold. Therefore, beginning in 1989, all late-run targets less than 10 m from the transducer on the left bank and less than 15 m on the right bank were excluded from chinook counts.

More recently, the theoretical validity of discriminating sockeye and chinook based on target strength has been questioned. Eggers et al. (1995) noted that the observed 12 dB difference in target strength modes from the 1985 and 1986 sonar data was inconsistent with predictions from most models of target strength versus length, given the observed length distributions of Kenai River sockeye and chinook salmon. These models, based on theoretical considerations as well as empirical data (MacLennan and Simmonds 1992), would have predicted approximately a 5 dB difference between sockeye and chinook salmon target strength modes.

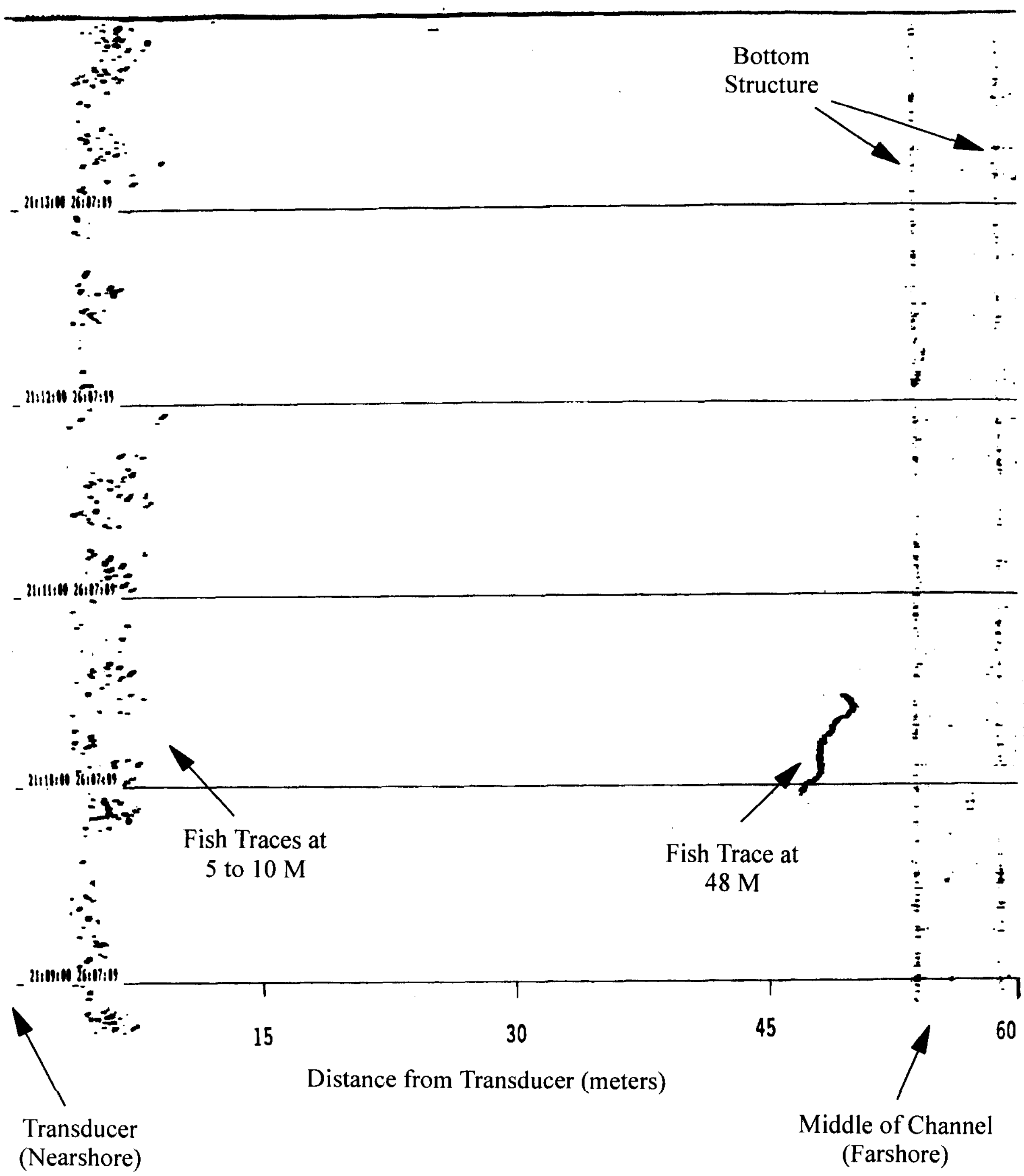


Figure 18.-Chart recording from 26 July 1989 showing probable sockeye salmon near shore.

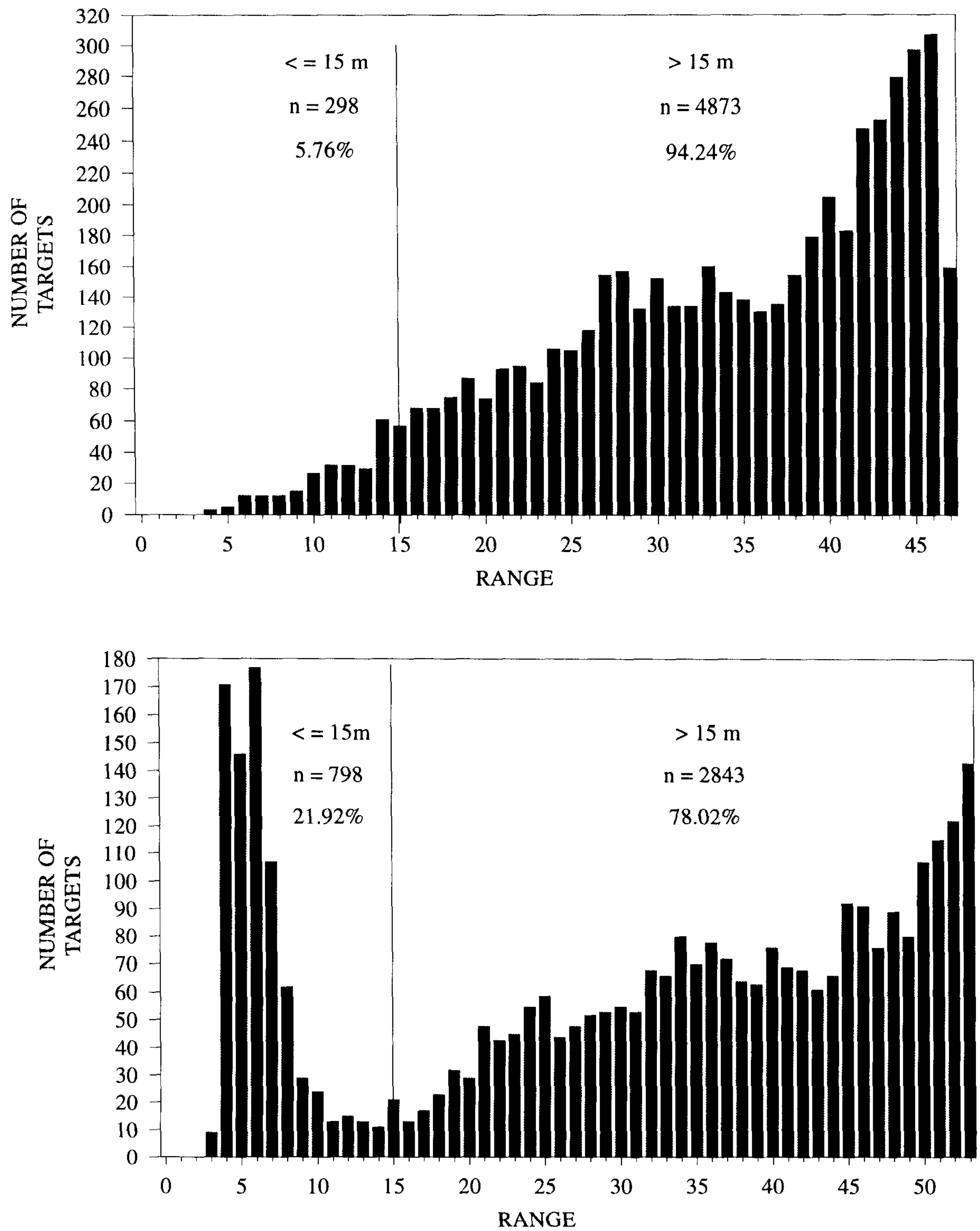


Figure 19.-Frequency distribution of range for all targets during entire early run of 1989 (top), and for the dates 9 July through 14 July 1989 of the late run (bottom).

Finally, Eggers (1994) created a stochastic computer model to simulate target-strength distributions under different mixtures of species and different interrogation rates (number of measurements per fish). His model assumed ideal conditions for sonar (low noise, low threshold). Using the length distributions of sockeye and chinook salmon observed on the Kenai River, and the interrogation rates achieved on the Kenai chinook sonar project, the model predicted that the resulting target strength distributions would be unimodal, not bimodal. Eggers concluded that, under idealized conditions, it would not be possible to discriminate Kenai River sockeye and chinook salmon based on mean target strength.

Analytical Methods

Because split-beam sonar estimates target strength more precisely than does dual-beam sonar, the split-beam system should be better able to discriminate between sockeye and chinook salmon. Frequency distributions of mean target strength were estimated from two split-beam data sets collected at the standard (high) threshold (Table 3). This threshold could be maintained throughout all tide stages. Of the two high-threshold data sets, there were more sockeye present during the late season than during the early season.

Low-threshold data were collected in order to capture more small echoes and perhaps enhance the probability of discriminating between sockeye and chinook (Table 4). Of the two low-threshold data sets, there were far more sockeye salmon present on 18 July than on 4 July. It takes from 12 hours to several days for sockeye to travel from the mile-8 chinook sonar site to the mile-19 sockeye sonar site (Ken Tarbox, ADF&G, Soldotna, personal communication). Sockeye passage at the mile-19 site was more than ten-fold greater on 18-21 July than on 4-7 July (Table 5). Frequency distributions of mean target strength were estimated for both low-threshold data sets.

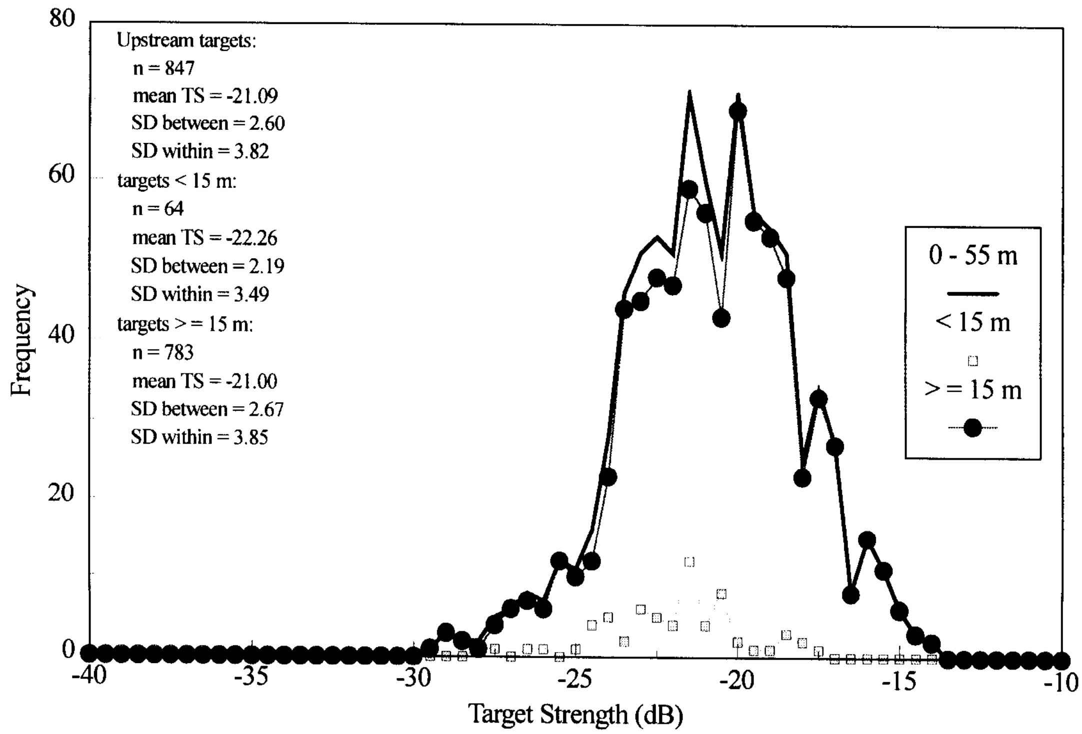
As discussed above, there is strong circumstantial evidence for spatial separation between sockeye salmon (nearshore) and chinook salmon (offshore). In particular, most targets within 15 m of the transducer on 18 July were probably sockeye salmon. Therefore we also compared the target strength distributions of nearshore fish (< 15 m from the transducer) with those of offshore fish (> 15 m).

Results

Upstream targets ensonified at a high threshold did not display a bimodal target strength distribution during either the early or late season (Figure 20). Nearshore (< 15 m range) targets were smaller on average than offshore (> 15 m) targets for both early- and late-season data sets (Z tests, $P < 0.001$), although the difference in mean TS was greater for the late-season data set (2.9 dB) than for the early-season data set (1.3 dB).

Low-threshold target-strength distributions (Figure 21, Figure 22) could possibly be interpreted as having small modes at -28 dB (4 July data) and -30 dB (18 July data); with narrow "notches" at -27.5 dB (4 July) and -29.5 dB (18 July). The multimodal appearance may also be due to sampling error (there was a total of only 936 low-threshold targets versus 2,123 high-threshold targets). Nearshore (< 15 m range) targets were smaller on average than offshore (> 15 m) targets (Z tests, $P < 0.001$), with a difference of 3.5 dB for the 4 July data and 2.8 dB for the 18 July data.

Offshore fish on 18 July were approximately 1.7 dB smaller on average than offshore fish on 4 July ($Z = 13.0$, $P < 0.001$).



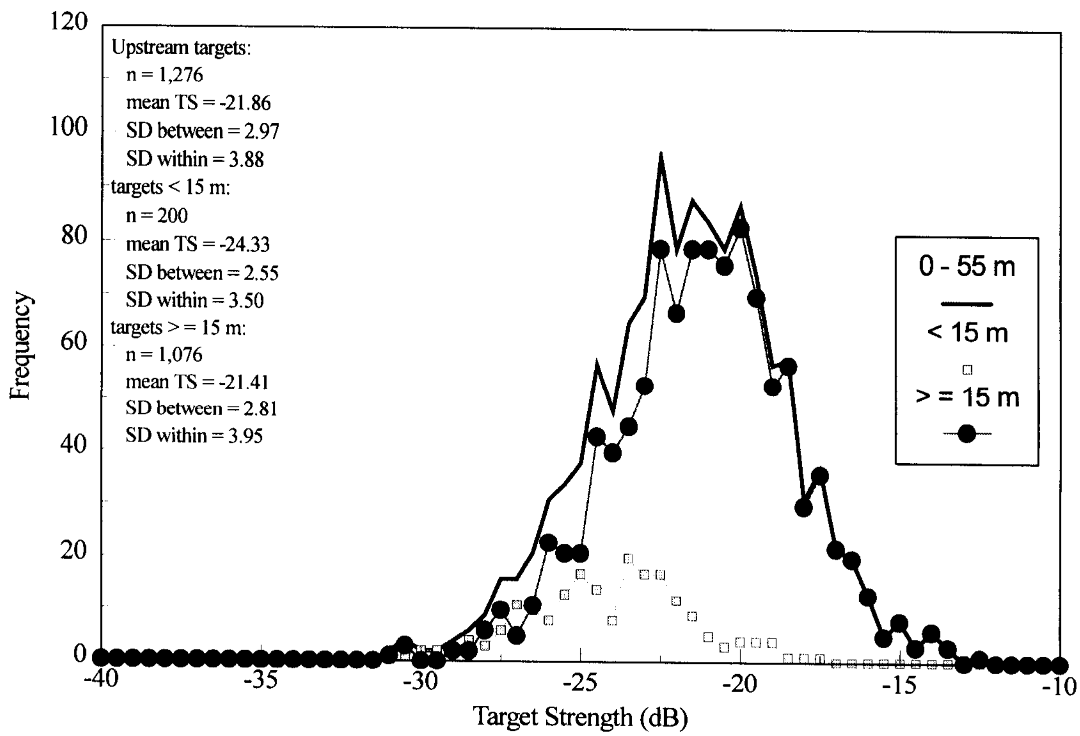
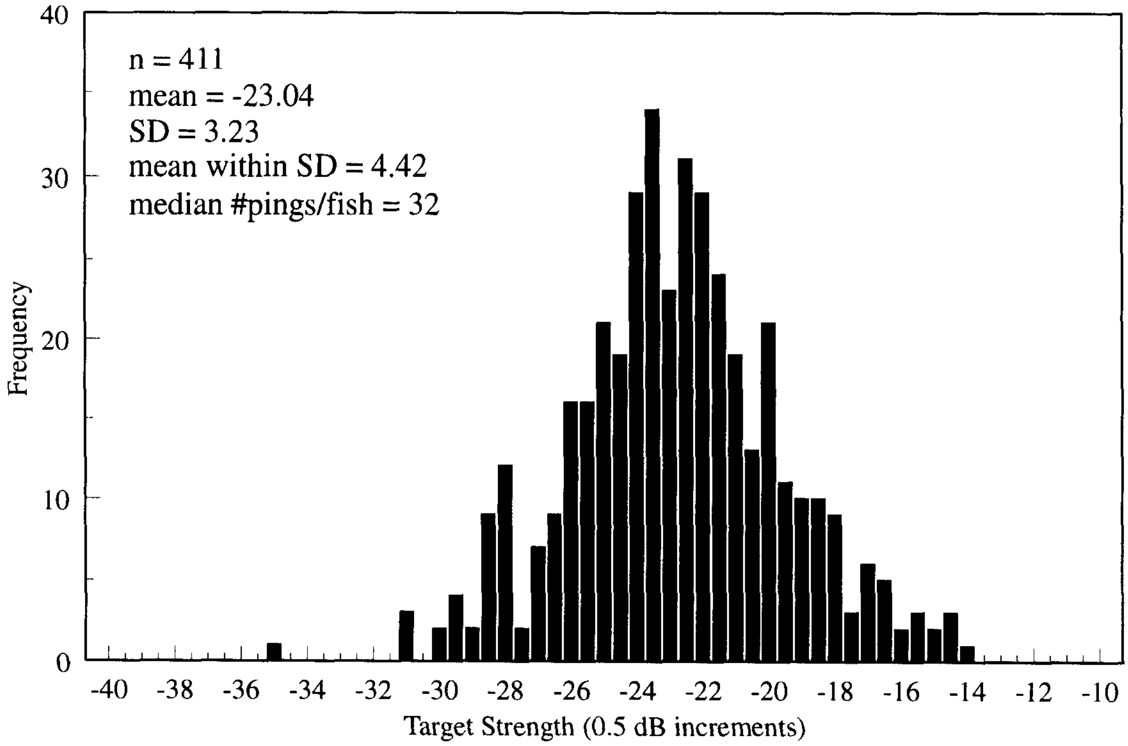


Figure 20.-Frequency distributions of target strength for all targets, for targets at ranges less than 15 m, and for targets at ranges greater than 15 m, from high-threshold data collected during the early run (top) and late run (bottom).



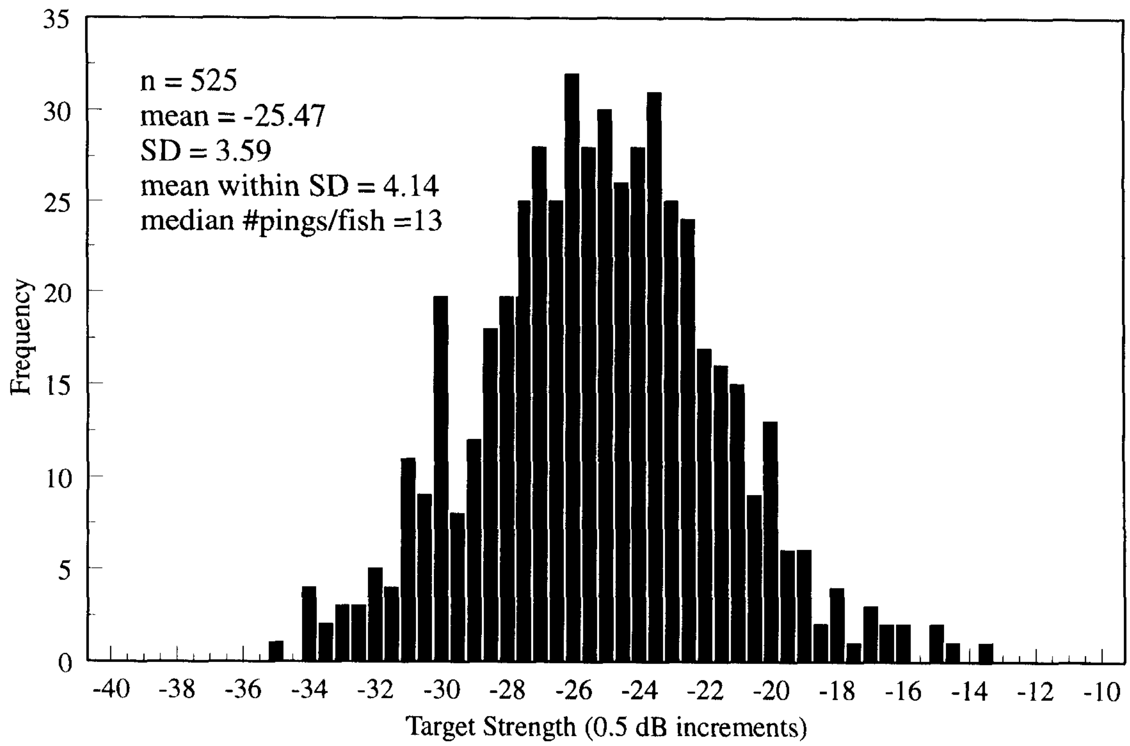


Figure 21.-Frequency distributions of target strength from low-threshold data collected on 4 July (top) and on 18 July.

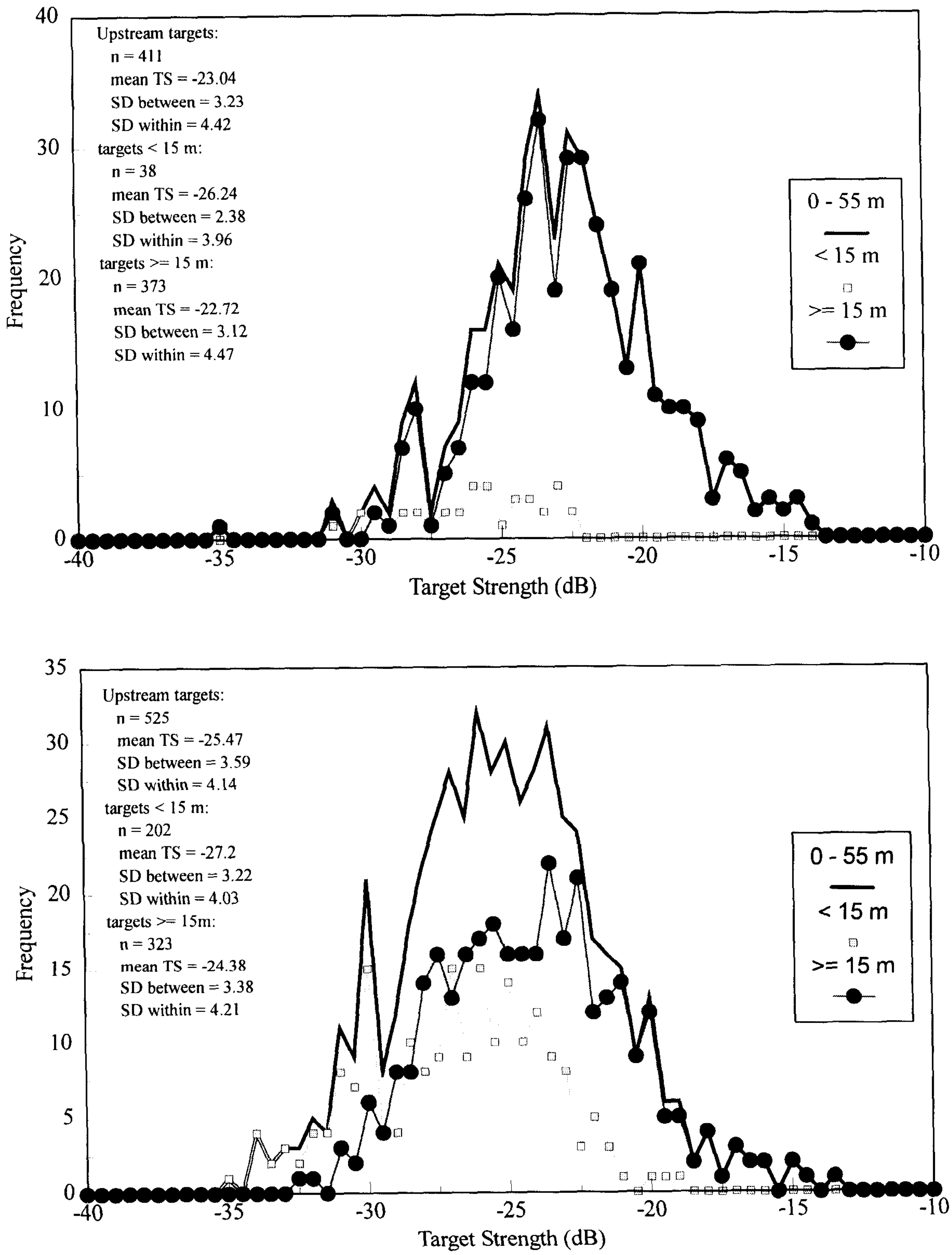


Figure 22.-Frequency distributions of target strength for all targets, for targets at ranges less than 15 m, and for targets at ranges greater than 15 m, from low-threshold data collected on 4 July (top) and 18 July (bottom).

Conclusions

At the high threshold, which could be maintained throughout all tide stages, mean target strength appears to provide little discriminatory power for separating Kenai River chinook from sockeye salmon. There was no evidence of bimodality in the target strength distribution from the late-season data set. Apparently, high within-fish and between-fish variability masks a relatively small difference in means. The high variability can be attributed to both the low signal-to-noise ratio found in riverine environments, and the change in aspect as the fish traverses the acoustic beam.

Superficially, it is tempting to conclude that the notches in the low-threshold target-strength distributions represent gaps between the respective sockeye and chinook salmon TS distributions. However, this hypothesis is inconsistent with our conclusions about spatial segregation, i.e., that the vast majority of nearshore targets are sockeye and that most offshore targets are chinook. On 4 July, most of the targets to the left of the notch (less than -27.5 dB) were offshore. On 18 July, most of the nearshore targets were to the right of the -29.5 dB notch. In order to conclude that the notch at -29.5 represents the break between sockeye and chinook, one would have to accept that the majority of the nearshore targets on 18 July were chinook salmon.

Whereas there is circumstantial evidence supporting spatial segregation of the two species (see "Accuracy of Dual-Beam Abundance Estimates"), we have no direct estimates of species composition by range at the mile-8 site. Given the 1.7 dB difference in mean TS between 4 July and 18 July offshore targets, it is possible that some sockeye salmon are migrating more than 15 m from the transducer and "contaminating" the chinook salmon target strength distribution.

OBJECTIVE 5: ACCURACY OF DUAL-BEAM ABUNDANCE ESTIMATES

Sources of Error

Results of this study may raise concern over the accuracy of dual-beam sonar estimates of chinook salmon abundance. This issue can best be addressed by discussing the relative importance of several potential sources of error. Abundance of chinook salmon could have been underestimated (or had a negative bias) because (1) they swim above or below the beam, (2) they swim inside the 10-15 m range cutoff during the late season, or (3) they swim behind the transducer. Conversely, chinook salmon abundance could have been overestimated (positive bias) because (4) early-run sockeye salmon (or late-run sockeye salmon swimming outside of the 10-15 m range thresholds) could have been misclassified as chinook if they exceeded the -28 dB TS threshold, or (5) downstream targets greater than -28 dB were included with the upstream targets. Each possible source of error will be addressed in turn.

1. Results of this study support what was previously thought, that few upstream-migrating fish escape detection by the dual-beam system (or the split-beam system) by swimming above the beam. Because of the strong orientation of fish to the bottom, the potential for missing fish under the beam is greater, if for example sound shadows exist or if the transducer is aimed too high. Although there is no direct way to test this, we believe that neither is a substantial source of error because of (1) the quality of the bottom profile (straight and even slope to the center of the river), (2) the muddy composition of the river bottom which allows the beam to be aimed close to the bottom, (3) constant monitoring of the aim, and (4) the physical size of chinook salmon.

2. In contrast, there are almost certainly some chinook salmon which swim closer than 10-15 m from the transducer during the late season. Approximately 6% of all targets in the early-run data set were less than 15 m from the transducer. Since there is an early run of sockeye which may comprise some of the 6%, it seems reasonable to conclude that the number of late-run chinook salmon excluded because of range thresholds is less than 6% of the total.
3. We conducted no new investigations to estimate the number of chinook salmon that swim behind the transducers, however given only 6% of targets out to 15 m range, it seems unlikely that substantial numbers of chinook swim between the transducers and shore. We can test this more directly with setnets in the future, but it is unlikely to be an important source of error.
4. This study could not confirm the validity of discriminating chinook salmon from sockeye salmon based on acoustic size. Fortunately, the two species appear to be spatially segregated to a large degree. Range thresholds were instituted early in the project's history and apparently have been effective at preventing the vast majority of sockeye from being counted as chinook salmon. There have been occasions, during the peak of large runs, when the sockeye distribution may (from the appearance of chart recordings, see Figure 18) have extended more than 10-15 m from the transducer. Project personnel have temporarily extended the range threshold out as far as 20 m under these conditions. However there may also be sockeye scattered in midriver which appear no different on the chart recordings, and at present we would have no means to detect such fish or to estimate their number. Given that sockeye can outnumber chinook many-fold, only a very small proportion of sockeye in midriver could have a substantial effect on chinook abundance estimates.
5. This study estimated higher proportions of downstream targets than had been found previously. However downstream targets were also found to be acoustically smaller, on average, than upstream targets; and the -28 dB target-strength threshold may have excluded a substantial fraction of downstream targets from consideration. Direction of travel has the potential to be one of the largest of the five sources of error discussed here, and additional data will be needed to quantify it.

In summary, there are three possible sources of negative bias in the dual-beam chinook salmon abundance estimates, and they are likely to be of relatively small magnitude. The two sources of positive bias are of unknown and possibly larger magnitude. Both of these latter biases, the first due to sockeye being counted as chinook in mid-river, and the second due to downstream targets being counted as upstream, need further investigation.

Comparison With Other Estimates and Indices

There are several lines of indirect evidence which indicate that the dual-beam sonar estimates have, at the very least, provided a useful index of chinook salmon abundance.

Chinook salmon passage was first estimated with sonar during the late run of 1987. A tag-and-recapture program also estimated chinook salmon abundance in the lower Kenai River from 1985 through 1989 (Hammarstrom and Larson 1986, Conrad and Larson 1987, Conrad 1988, Carlon and Alexandersdottir 1989, Alexandersdottir and Marsh 1990; Table 9). Tagging estimates had low precision and a positive bias, especially during the late run (Bernard and Hansen 1992).

Table 9.-Sonar and mark-recapture abundance estimates with 95% confidence intervals for early and late runs of chinook salmon, 1987-1989.

	SONAR		TAGGING	
Year	Early Run[a]	Late Run[b]	Early Run	Late Run
1987	no estimate[c]	48,123	25,643	65,024
		no estimate	[16,632, 34,653]	[16,824, 113,224]
1988	20,880	52,008	25,047	110,869
	[19,976, 21,784]	[50,013, 54,003]	[15,684, 34,410]	[61,589, 160,149]
1989	17,992	29,035	23,253	57,279
	[17,295, 18,689]	[27,676, 30,394]	[9,702, 36,804]	[26,554, 88,004]

[a] Early run occurs 16 May-30 June

[b] Late run occurs 1 July-mid August

[c] Only operated from 3 June-30 June

Therefore comparing the sonar and tagging estimates is most meaningful for the early run. The tagging estimates were 19% and 29% greater than the sonar estimate for 1988 and 1989, respectively, and in both cases the sonar estimate was within the 95% confidence interval for the tagging estimate. In view of the potential positive bias of the tagging estimate, the sonar and tagging estimates were in good agreement. Also, the daily catch of chinook salmon per unit fishing effort (CPUE) for the drift gillnets used in the tagging study tracked well with the daily sonar estimates (Figure 23).

Late-run sockeye salmon outnumber chinook salmon (whether estimated by sonar or tag-and-recapture) in the Kenai River by more than an order of magnitude. If, in fact, any significant number of sockeye salmon were being systematically misclassified as chinook salmon, one would expect some correlation between the estimates of chinook salmon passage at river mile 8 and estimates of sockeye salmon abundance at river mile 19 during the late run. To the contrary, variation in total abundance and run-timing for late-run chinook as estimated by sonar at river mile 8 cannot be explained by the corresponding sockeye data from the sonar at river mile 19 (Table 10). Annual estimates of chinook and sockeye abundance are not correlated (Pearson's $r = 0.02$, $P = 0.96$; Spearman's $\rho = -0.02$, $P = 0.96$; Kendall's $\tau = -0.07$, $P = 0.80$). In fact, except for 1994 when both sonar estimates increased from the preceding year, the chinook salmon seasonal estimates move in the opposite direction of the sockeye seasonal estimates with respect to the previous year's estimate (i.e., when sockeye salmon seasonal estimates increased from the preceding year, chinook salmon seasonal estimates decreased and vice versa). As an example, note that the late-run estimate of chinook salmon fish fell from 52,008 to 29,035 fish from 1988 to 1989. Sockeye salmon on the other hand, were estimated to increase in number from

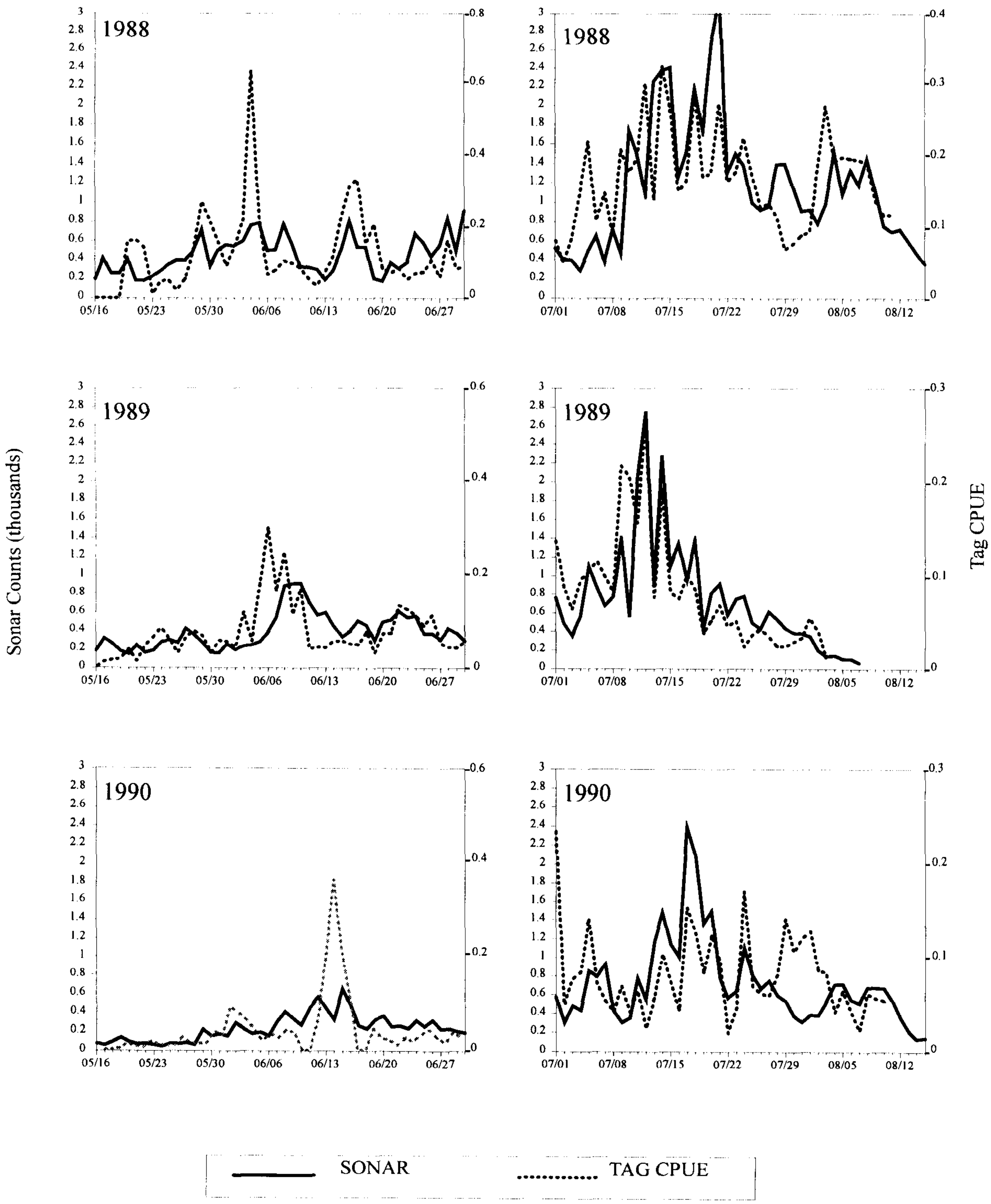


Figure 23.-Daily estimates of chinook salmon passage (thousands) and daily catch per unit fishing effort (fish per net minute drifted) of chinook salmon in tagging studies for the early (left) and late (right) runs, 1988 through 1990.

Table 10.-Comparison of late-run Kenai River chinook salmon sonar estimates (river mile 8) and Kenai River sockeye sonar estimates (river mile 19) for 1987-1994.

Year	Total Sockeye	Total Chinook	Date Peak Sockeye	Total Count on Peak Sockeye	Date Peak Chinook	Total Count on Peak Chinook	Chinook Count on Sockeye Peak Date	Chinook Count Day Before Sockeye Peak Date
1987	1,596,87	48,15	7/2	150,29	7/2	3,73	3,73	3,70
1988	1,021,46	52,00	7/2	112,28	7/2	3,71	1,60	1,30
1989	1,599,95	29,03	7/2	127,38	7/1	2,76	91	82
1990	659,52	33,47	7/1	92,67	7/1	2,39	2,11	2,39
1991	647,59	34,61	7/2	59,01	7/1	3,11	60	75
1992	994,79	30,31	7/2	83,18	7/2	1,95	1,71	71
1993	813,61	49,67	7/1	88,38	7/1	3,34	3,11	3,34
1994	1,003,44	53,28	8/	95,47	7/1	4,69	1,22	1,03

1,021,469 in 1988 to 1,599,959 in 1989. In fact, 1989 was the lowest estimate of late-run chinook salmon abundance on record (as estimated at river mile 8), and 1989 was the highest recorded return for sockeye salmon (as estimated at river mile 19). The late-run tagging estimate of abundance for 1989 was also the lowest estimate generated by that project between 1987 and 1989.

Finally, patterns of migratory timing between the mile-8 and mile-19 sonar projects were often quite dissimilar. In 1989, 1991, and 1994 peak of the sockeye run was 9, 10, and 16 days after the peak of the chinook salmon run (Table 10).

RECOMMENDATIONS

1. **Replace dual-beam system with split-beam system.**

   The use of split-beam technology would improve the accuracy with which the project estimates chinook salmon passage. The primary advantage would be derived from knowing the direction of travel for each target. Counts could eventually be adjusted to account for downstream targets on a daily basis. The ability to determine the spatial position of each target also provides a diagnostic tool in assessing whether the transducer is properly aimed along the bottom of the river. Knowing the spatial distribution of all targets also provides important descriptive information about fish behavior under changing environmental conditions. The ease with which split-beam systems can be field-calibrated would allow more frequent and reliable *in situ* calibration verifications, which would facilitate detecting equipment malfunctions or changes in system performance.

2. **Replace 420 kHz with a lower frequency system.**

   The primary advantage of the lower frequency was an improved signal-to-noise ratio (SNR). Higher SNR's resulted in less interference from boat wake, improved tracking capabilities, more precise target strength measurements, and improved target detection (by allowing lower relative detection thresholds).

3. **Investigate range distribution of sockeye and chinook salmon.**

   Results reported herein support the conclusion of Eggers et al. (1995), that exclusion of the majority of sockeye from chinook salmon estimates has been primarily achieved through spatial segregation between the two species. However, even a very small fraction of the sockeye population swimming beyond the 15 m cutoff could impart a substantial bias to the chinook salmon estimates. To further assess the potential for such errors, we recommend that the distribution of both species be investigated further. The most obvious solution would be to initiate a pilot netting program in the lower river. Large-mesh gillnets could be set behind the transducer to test for presence/absence of chinook near shore; and carefully controlled drifts with small mesh could be used to test for presence/absence of sockeye offshore. If substantial numbers of either were detected, a more elaborate netting program could be considered, using multiple mesh sizes to estimate species proportions.

4. **Eliminate the target-strength threshold.**

   Use of a target-strength threshold for excluding sockeye salmon is no longer justified, since we have no evidence that it is effective at excluding sockeye salmon. This would actually have very little effect on the estimates, since only a very small number of targets (~ 1% in 1994) have been excluded based on target strength. We recommend that the voltage or detection threshold be selected as it has been in the past, by finding the lowest threshold value that can be maintained through all tide stages while maintaining an aim close to the bottom of the river. This system has the advantage of being insensitive to calibration errors or fluctuations in system performance, because (1) there is no fixed target-strength threshold, and (2) the voltage threshold is keyed to the river itself.

   We cannot say with finality that discriminating Kenai River chinook from sockeye salmon with target strength is impossible. Recent advances in hydroacoustic technology have enabled greater signal-to-noise ratios which presumably would result in more precise estimates of target strength. However a very large increase in precision would be necessary for our purposes, and this seems unlikely. We recommend that target strength continue to be monitored, but not necessarily in order to discriminate species. Target strength may be useful for estimating the composition of downstream targets.

5. **Monitor direction of travel.**

   We need additional data in order to make an informed decision on how to use direction-of-travel information. Data presented in this report would indicate that estimates of chinook salmon abundance would be substantially reduced by incorporating such information, however 1994 data were limited and may not reflect seasonal averages. Furthermore, the amount of the reduction depends on the composition of the downstream targets. Downstream traveling sockeye salmon or debris should be subtracted once from the total count, whereas chinook salmon which temporarily drift back down past the sonar site should be subtracted twice (once for the downstream count and once to negate a previous upstream count).

We recommend that a full season of split-beam data on direction of travel be collected in 1995, before procedures are finalized for utilizing such information. In the interim, we recommend that daily counts be reported as they have in the past (total count regardless of direction of travel), in order to preserve continuity with past estimates. In addition, the daily proportion of downstream targets could be reported to fishery managers. After the 1995 season, methods can be explored for identifying debris or otherwise estimating the composition of downstream targets. Future analyses of direction of travel data should include a comparison of the trajectories of upstream and downstream migrants through the beam. If the overall proportion of downstream targets remains high and has a substantial effect on the seasonal counts, then proposed adjustments to current escapement goals can be formulated.

6. Try a different transducer on the right bank.

Surface noise, particularly boat wake, has been an important factor limiting sonar sampling on the right bank. During 1994, there were long periods with heavy boat traffic when the right bank could not be sampled. Spatial distribution results reported here demonstrate that a very large proportion of upstream fish travel in the bottom half of the beam. Other results suggest that most boat wake is confined to the upper half of the beam. We recommend that a different transducer, narrower in the vertical dimension, be obtained and tested on the right bank to determine whether the effect of surface noise can be substantially reduced.

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APPENDIX A.

Appendix A1.-Calibration measurements, settings, and tracking parameters for the dual-beam sonar system data presented in this report.

System Calibration Measurements	
Source level	212.688 dB
Through-system gain	-172.597 dB
TVG starting range	2.5 m
Wide-beam drop-off correction	1.34
System Settings	
Transmit power	-10 dB
Receiver gain	0 dB
Pulse repetition rate	8 sec^{-1}
Pulse width	0.4 ms
Band width	5 kHz
Narrow-beam threshold	900 mV
Wide-beam threshold	900 mV
System Tracking Parameters	
Minimum -6 dB pulse width accepted	0.200 msec
Maximum -6 dB pulse width accepted	0.734 msec
Minimum beam pattern factor accepted	-12 dB
Minimum pings per fish	5
Maximum change in range	1.9 m
Maximum time between pings	1.0 sec

APPENDIX B.

Appendix B1.-Estimation of target strength.

Target strength, in decibels (dB), of an acoustic target located at range R (in m), θ degrees from the maximum response axis (MRA) in one plane and ϕ degrees from the MRA in the other plane is estimated as:

$$TS = 20 \log_{10}(V_o) - SL - G_r + 40 \log_{10}(R) + 2\alpha R - G_{TVG} - 2B(\theta,\phi)$$

where:

V_o	= voltage of the returned echo, output by the echo sounder,
SL	= source level of transmitted signal in dB,
G_r	= receiver gain in dB,
$40 \log_{10}(R)$	= two-way spherical spreading loss in dB,
$2\alpha R$	= two-way absorption loss in dB,
G_{TVG}	= time-varied-gain correction of the echo sounder, and
$2B(\theta,\phi)$	= two-way loss due to position of the target off of the MRA.

The source level and gain are measured during calibration and confirmed using *in situ* standard sphere measurements. The time-varied-gain correction compensates for spherical spreading loss. Absorption loss ($2\alpha R$) was not corrected for in this study.

In practice, the location of the target in the beam (θ and ϕ) is not known, so $B(\theta,\phi)$ must be estimated in order to estimate target strength. Dual-beam and split-beam sonar differ in how they estimate $B(\theta,\phi)$, also called the beam pattern factor.

Dual-beam sonar (Ehrenberg 1983) uses one wide and one narrow beam. The system transmits on the narrow beam only and receives on both. The ratio between the voltages of the received signals is used to estimate beam pattern factor:

$$B(\theta,\phi) = 20 \log(V_N/V_W) \bullet WBDO$$

where V_N is the voltage of the returned echo on the narrow beam, V_W is the voltage of the echo on the wide beam, WBDO is the wide beam dropoff correction, specific to each transducer, and estimated at calibration.

Split-beam sonar (MacLennan and Simmonds 1992) estimates target location (angles θ and ϕ of the target from the MRA) directly, not just the beam pattern factor ($B(\theta,\phi)$). Split-beam transducers are divided into four quadrants, and θ and ϕ are estimated by comparing the phases of signals received by opposing pairs of adjacent quadrants. The beam pattern factor is a function of θ and ϕ, determined during laboratory calibration.

APPENDIX C.

Appendix C1.-Sonar calibration measurements, equipment settings, and tracking parameters for the split-beam sonar data presented in this report.

100	-1	1	MUX argument #1 - multiplexer port to activate
101	-1	0	percent - sync pulse switch, ping rate determiner NUS
102	-1	32767	maxp - maximum number of pings in a block NUS
103	-1	32767	maxbott - maximum bottom range in samples NUS
104	-1	3	N_th_layers - number of threshold layers
105	-1	5	max_tbp - maximum time between pings in pings
106	-1	5	min_pings - minimum number of pings per fish
507	-1	FED5	timval - 0xFED5 corresponds to about 20 kHz NUS
108	-1	1	mux_on - means multiplexing enabled on board NUS
109	-1	200	mux_delay - samples delay between sync and switching NUS
110	-1	0	decimate_mask - decimate input samples flag NUS
111	-1	3	plot_up_fish - number of fish between stbar updates
112	-1	0	echogram_on - flag for DEP echogram enable 0=off, 1=on
113	-1	1	f_inst->o_raw - write raw file flag 1 = on, -1 or 0= off
114	-1	1	f_inst->o_ech - write echo file flag 1 = on, -1 or 0= off
115	-1	1	f_inst->o_fsh - write fish file flag 1 = on, -1 or 0= off
116	-1	1	f_inst->o_sum - write summary table file flag 1 or 0= on
117	-1	0	print summary table on printer, 1 = on, -1 or 0 = off
118	-1	15	maxmiss - maximum number of missed pings in auto bottom
119	-1	1	bottom_code - bottom tracking, 0=fix, 1=man, 2=auto
120	-1	0	sb_int_code - sb only=0, sb-int: 40log a bot=1, 20log=2
121	-1	0	sb_int_code2 - sb only=0, sb-int 40log eg=0, 20log=1
122	-1	1	N_int_layers - number of integration strata
123	-1	1	N_int_th_layers - number of integration threshold strata
124	-1	0	int_print - print integrator interval results to printer
125	-1	0	circular element transducer flag for bpf calculation
126	-1	80	grid spacing for Model 404 DCR (in samples, 16 s/m)
127	-1	2	TRIG argument #1 - trigger source
128	-1	0	TRIG argument #2 - digital data routing
129	-1	2	FILTER argument #1 - filter number
200	-1	0.0000	sigma_flag - if != 0.0000, sigma is output, not ts
201	-1	220.7400	sl - transducer source level
202	-1	-169.8600	gn - transducer through system gain at one meter
203	-1	-18.0000	rg - receiver gain used to collect data
204	-1	2.5000	narr_ax_bw - vertical axis nominal beam width
205	-1	10.0000	wide_ax_bw - horizontal axis nominal beam width
206	-1	0.1950	narr_ax_corr - vertical axis phase correction
207	-1	0.0000	wide_ax_corr - horizontal axis phase correction
208	-1	8.0000	ping_rate - pulses per second

-continued-

209	-1	0.0000	echogram start range in meters
210	-1	70.0000	echogram stop range in meters
211	-1	900.0000	echogram threshold in millivolts
212	-1	5.0000	print width in inches
213	-1	-45.0000	ts plot minimum target strength in dB
214	-1	-15.0000	ts plot maximum target strength in dB
215	-1	0.0000	range plot minimum in meters
216	-1	70.0000	range plot maximum in meters
217	-1	-1.8000	min_angoff_v - minimum angle off axis vertical
218	-1	1.8000	max_angoff_v - maximum angle off axis vertical
219	-1	-6.0000	min_angoff_h - minimum angle off axis horiz.
220	-1	6.0000	max_angoff_h - maximum angle off axis horiz.
221	-1	-24.0000	max_dB_off - maximum angle off axis in dB
222	-1	-8.2094	ux - horizontal electrical to mechanical angle ratio
223	-1	-28.2811	uy - vertical electrical to mechanical angle ratio
224	-1	0.0000	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	-0.017688	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.637955	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	-0.015195	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.076042	ud_coef_e - e coeff. for up-down beam pattern eq.
229	-1	0.0000	lr_coef_a - a coeff. for left-rt beam pattern eq.
230	-1	0.107493	lr_coef_b - b coeff. for left-rt beam pattern eq.
231	-1	-0.263569	lr_coef_c - c coeff. for left-rt beam pattern eq.
232	-1	-0.000137	lr_coef_d - d coeff. for left-rt beam pattern eq.
233	-1	-0.000112	lr_coef_e - e coeff. for left-rt beam pattern eq.
234	-1	15.0000	maximum fish velocity in meters per second
235	-1	10.0000	thd_up_time - minutes between 3d plot updates
236	-1	0.6000	maxpw - pulse width search window size in ms NUS
237	-1	1.5000	cltop - start of processing in meters
238	-1	60.0000	bottom - bottom depth in meters
239	-1	0.0000	init_slope - initial slope for tracking in m/ping
240	-1	1.0000	exp_const - exponent for expanding tracking window
241	-1	0.3500	max_ch_rng - maximum change in range in m/ping
242	-1	0.3000	pw_criteria->min_pw_6 - min -6 dB pulse width
243	-1	0.6000	pw_criteria->max_pw_6 - max -6 dB pulse width
244	-1	0.0000	pw_criteria->min_pw_12 - min -12 dB pulse width
245	-1	2.0000	pw_criteria->max_pw_12 - max -12 dB pulse width
246	-1	0.0000	pw_criteria->min_pw_18 - min -18 dB pulse width
247	-1	2.0000	pw_criteria->max_pw_18 - max -18 dB pulse width
248	-1	1.0000	Intake width to weight fish to (in meters)

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249	-1	10.0000	maximum echo voltage to accept (Volts - peak)
260	-1	0.0000	minimum absolute distance fish must travel in x plane
261	-1	0.0000	minimum absolute distance fish must travel in y plane
262	-1	0.0000	minimum absolute distance fish must travel in z plane
263	-1	2.0000	bottom_window - auto tracking bottom window (m)
264	-1	3.0000	bottom_threshold - auto tracking bottom threshold (V)
401	0	20.0000	th_layer[0] - bottom of first threshold layer (m)
401	1	70.0000	th_layer[1] - bottom of second threshold layer (m)
401	2	100.0000	th_layer[2] - bottom of third threshold layer (m)
402	0	900.0000	th_val[0] - thr. for 1st layer (mV)
402	1	900.0000	th_val[1] - thr. for 2nd layer (mV)
402	2	9999.0000	th_val[2] - thr. for 3rd layer (mV)
403	0	1.0000	Integration layer 1 top (m)
403	1	20.0000	Integration layer 1 bottom (m)
404	0	20.0000	Integration threshold layer 1 bottom (m)
405	0	100.0000	Integration threshold layer 1 value (mV)
601	-1	HTI-SB-200kHz	Echo sounder type
602	-1	SN-92-005	Echo sounder serial number
603	-1	HTI-SB-2X10	Transducer type
604	-1	SN-316613	Transducer serial number
605	-1	Spd-2	Echogram paper speed
606	-1	9_pin	Echogram resolution
607	-1	Board_Ext	Trigger option
608	-1	Left_to_Right	River flow direction
609	-1	All_Fish	Fish included in 3d plot
610	-1	OFF	Echogram enable flag
611	-1	D:\KENAISB\K	Drive and first letter to send files

*
* The following parameters are DES parameters used only in remote
* operation. In non-remote operation, they are stored but ignored.
*

250	-1	0.4000	TX argument #1 - pulse width in milliseconds
251	-1	25.0000	TX argument #2 - transmit power in dB-watts
252	-1	-6.0000	RX argument #1 - receiver gain
253	-1	125.0000	REP argument #1 - ping rate in ms per ping
254	-1	10.0000	REP argument #2 - pulsed cal tone separation
255	-1	1.0000	TVG argument #1 - TVG start range in meters
256	-1	100.0000	TVG argument #2 - TVG end range in meters
257	-1	40.0000	TVG argument #3 - TVG function (XX Log Range)
258	-1	-12.0000	TVG argument #4 - TVG gain
259	-1	0.0000	TVG argument #5 - alpha (spreading loss) in dB/km

APPENDIX D.

Appendix D1.-Examples of output files generated by the split-beam sonar tracking program.

.ECH File

File Header

* Processing File e:\sb94\185\R185_1.RAW using C:\SB\SBPORT1.PAR Fri Sep 30 15:58:22 1994
* Start File Processing at Port 1 C:\SB\SBPORT1.PAR Mon Jul 04 00:00:01 1994
* Data processing parameters used in collecting this file for Port 1

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{Program lists all the collection and processing parameters here}

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* Fish * Num.	Ping Num.	X dir. Coord.	Y Dir. Coord.	Range meters	-6 PW	-12 PW	-18 PW	Sum Volts	Beam P. Factor	Target Strength
1	396	2.52	-0.01	24.61	16	23	24	1.5486	-8.7724	-20.31
1	399	2.17	-0.27	24.68	20	28	32	2.3635	-7.4514	-17.96
1	400	2.00	-0.07	24.82	14	18	19	1.3563	-5.4490	-24.78
1	401	2.31	-0.09	24.63	16	23	25	2.8622	-7.4280	-16.32
1	402	2.28	-0.23	24.63	18	22	27	1.6054	-7.8259	-20.94
1	403	2.23	-0.32	24.71	20	26	32	3.9340	-8.1340	-12.85
1	404	1.91	-0.32	24.69	21	29	33	2.4886	-6.4467	-18.51
1	405	1.90	-0.27	24.72	20	27	31	4.7452	-5.8671	-13.49
1	406	1.68	-0.18	24.69	24	32	34	2.0259	-4.2557	-22.49
1	407	1.99	-0.24	24.66	27	35	38	2.7309	-6.1221	-18.03
1	409	1.46	-0.29	24.74	20	24	29	5.6712	-4.0563	-13.75
1	410	1.28	-0.22	24.74	18	26	30	4.8075	-2.8777	-16.36
1	411	1.59	-0.30	24.85	21	31	33	2.8310	-4.5909	-19.25
1	412	1.05	-0.23	24.66	18	24	28	2.3384	-2.2326	-23.27
1	413	0.98	-0.14	24.71	25	32	38	3.1240	-1.5465	-21.44
1	414	1.03	-0.11	24.65	18	27	38	5.3508	-1.5953	-16.72
1	415	1.02	-0.18	24.66	16	23	25	3.8046	-1.8392	-19.43
1	416	1.28	-0.37	24.68	18	22	25	2.4019	-4.1330	-21.14

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E:\SB94\RETRACK\R2731558.ECH
* Stop of Raw File. C:\SB\SBPORT1.PAR Mon Jul 04 10:45:11 1994

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.FSH File

File Header

* Processing File e:\sb94\185\R185_1.RAW using C:\SB\SBPORT1.PAR Fri Sep 30 15:58:22 1994
* Start File Processing at Port 1 C:\SB\SBPORT1.PAR Mon Jul 04 00:00:01 1994
* Data processing parameters used in collecting this file for Port 1
100 -1 1
101 -1 0
102 -1 32767
103 -1 32767
104 -1 3

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{Program lists all the collection and processing parameters here}

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*Fish #	Start Ping	End Ping	# Echo	Start Xcoord	Start Ycoord	Range meters	Dist X	Dist Y	Dist Z	Swim. Speed	Target Strength	TS STD	Mux Port
1	396	453	45	2.52	-0.01	24.61	-3.73	-0.48	-0.67	2.36	-21.59	4.393	1
2	531	544	12	-2.67	0.12	45.10	-1.73	-0.26	-0.23	4.71	-22.52	3.127	1
3	1971	1998	22	-0.66	-1.16	44.83	4.83	0.27	0.00	2.41	-12.89	5.315	1
4	2726	2737	5	-0.36	-0.06	8.73	-0.18	-0.11	0.14	1.05	-27.06	2.425	1
5	2714	2735	17	0.72	-0.03	8.18	-1.23	-0.09	0.73	1.21	-24.02	3.001	1
6	2858	2872	7	1.01	-0.45	15.24	-1.33	-0.02	0.12	0.94	-22.03	2.285	1
7	3346	3357	5	1.93	-0.66	25.25	-0.50	0.01	-0.19	0.67	-18.30	4.938	1
8	3373	3389	10	0.41	-0.69	23.72	-0.92	0.00	-0.36	1.45	-22.11	4.081	1
9	3896	3910	5	-0.91	-0.44	37.15	0.15	-0.13	-0.06	0.98	-31.02	0.734	1
10	3930	3965	23	2.59	-0.71	31.31	-2.39	-0.11	0.48	1.96	-20.64	4.933	1
11	4498	4541	26	1.43	-0.36	25.73	-3.59	0.25	0.57	1.55	-25.15	4.300	1
12	5041	5058	6	0.85	-0.09	11.87	-1.26	-0.04	-0.23	0.68	-27.23	2.840	1
13	5061	5068	7	-1.76	-0.51	47.93	0.76	-0.06	-0.15	2.33	-28.91	1.562	1
14	5715	5743	18	1.53	-0.53	24.88	-0.01	-0.13	0.39	1.62	-20.74	5.724	1
15	5832	5844	6	1.88	-0.80	31.14	-0.20	-0.10	0.34	0.83	-21.59	1.500	1
16	5845	5858	6	1.01	-0.80	32.01	0.69	-0.02	0.06	2.10	-24.64	3.689	1
17	5863	5898	19	0.76	-0.82	32.60	-0.55	-0.10	-0.36	1.60	-21.37	3.718	1